ECF No. 281-15, Ex. 11 to Plaintiffs' Mot. for Class Certification

Duplicate: ECF No. 307-10, Ex. 10 to Plaintiffs' Opp. to Mots. to Exclude

REDACTED VERSION REFILED PURSUANT TO DKT. 350

Exhibit 11

EXPERT REPORT OF DR. TIMOTHY ROUGHGARDEN

December 22, 2020

DZ Reserve, et. al. v. Facebook, Inc. (N.D. Cal.)

Case No. 3:18-cv-04978-JD

I. Qualifications

1. I am a Professor of Computer Science at Columbia University. Prior to joining Columbia, I was a Professor of Computer Science at Stanford University for 15 years. In addition, I have been a Visiting Professor at the London School of Economics.

2. In addition to my academic positions, I have served on the editorial board of nine journals, on the scientific advisory board of the Simons Institute in Berkeley, as the Chair of the Committee for the Advancement of Theoretical Computer Science, and as the general or program chair for five major conferences and numerous workshops. I have received many major awards, including the Social Choice and Welfare Prize (a prize for scholarship in social choice theory and welfare economics), the Presidential Early Career Award for Scientists and Engineers (PECASE), the ACM Grace Murray Hopper Prize, and a Guggenheim Fellowship.

3. I hold a Ph.D. degree (2002) in Computer Science from Cornell University, an M.S degree (1998) in Computer Science from Stanford University, and a B.S. degree (1997) in Applied Mathematics from Stanford University. My curriculum vitae is attached as **Exhibit 1.**

4. Much of my research over the last 15+ years has been focused on algorithmic game theory, including auction and mechanism design.

5. I am one of the leading researchers in the field of algorithmic game theory (also known as "economics and computation"). Algorithmic game theory is at the interface of economics and computer science. I co-edited and authored two chapters in one of the seminal books on

algorithmic game theory, *Algorithmic Game Theory*, Cambridge University Press, 2007. I also wrote the primary textbook in the field, *Twenty Lectures on Algorithmic Game Theory*, Cambridge University Press, 2016. I have also lectured extensively on algorithmic game theory, including in my Stanford courses Algorithmic Game Theory and Frontiers in Mechanism Design.

6. Algorithmic game theory includes the study of auction and mechanism design. I have researched and taught about auction and mechanism design, including second-price auctions and Vickrey-Clarke-Groves ("VCG") auctions. I have written many papers on VCG auctions. For example, I co-authored "Optimal Mechanisms for Combinatorial Auctions and Combinatorial Public Projects via Convex Rounding," *Journal of the ACM*, 63(4):Article 30, September 2016. I am also the co-author of "Robust Auctions for Revenue via Enhanced Competition," *Operations Research,* 68(4):1074--1094, June 2020. Both papers study VCG mechanisms. My textbook *Twenty Lectures on Algorithmic Game Theory* (Cambridge University Press, 2016) also covers second-price auctions, and more generally the VCG mechanism. My "Incentives in Computer Science" course, which I've taught at both Stanford and Columbia, covers VCG auctions and their applications in online advertising.

7. In the past four years, I have testified in one case: Looksmart Group, Inc. vs. Microsoft Corporation, Case No. 17-cv-04709-JST (N.D. Cal.).

II. Assignment and Summary of Opinions

8. I have been retained by Plaintiffs' Counsel (Cohen Milstein Sellers & Toll PLLC) in *DZ Reserve, et. al. v. Facebook, Inc.* (N.D. Cal.).

9. For my work in this matter, I will be reimbursed for my time at my typical hourly rate of $1,000. My compensation is in no way contingent on the opinions I provide or on the outcome of this case.

10. I understand that Plaintiffs allege that Facebook's Potential Reach metric is misleading, inflated, and fraudulent. Plaintiffs allege that Facebook represents that Potential Reach is a measurement of people, but that Potential Reach does not measure people, and at best, measures accounts.[1]

11. I have been asked to evaluate and opine on the following issues in connection with the damages caused by Facebook's misleading Potential Reach metric for a potential class of purchasers of Facebook Advertisements[2] since August 14, 2014.

12. I have been asked to evaluate and opine on how changes in demand for Facebook Advertisements caused by Facebook's misleading Potential Reach metric impacted the prices for Facebook Advertisements. Specifically:

---

[1] Plaintiffs' Third Amended Consolidated Class Action Complaint, *DZ Reserve v. Facebook, Inc.*, at ¶ 68.

[2] "Facebook Advertisements" include advertisements placed on Facebook platforms, including Facebook and Instagram. It is my understanding that Facebook produced data reflecting Facebook Advertisements purchased between August 15, 2014 and May 5, 2019.

13. *First*, I have been provided the results of Dr. Greg Allenby's conjoint survey. Dr. Allenby's conjoint survey measures the shift in advertiser budget allocations due to (a) providing a 10% minimum artificial increase in the value of the Estimated Potential Reach After Targeting and (b) representing that the United States Audience Size is 240,000,000 people rather than 180,000,000 people (the "Conjoint-Tested Potential Reach Misrepresentations").[3] I have been asked to analyze and measure how the shift in budget allocations caused by the Conjoint-Tested Potential Reach Misrepresentations impacted the prices paid by Facebook Advertisement purchasers. In other words, I have been asked to measure the difference in the prices paid by Facebook Advertisement purchasers between the as-is world (where Facebook disseminates the Conjoint-Tested Potential Reach Misrepresentations) and the but-for world (where Facebook does not disseminate the Conjoint-Tested Potential Reach Misrepresentations).

14. *Second,* I have been instructed by counsel to assume that removing the Potential Reach metric would cause an 8.5% decrease in aggregate advertiser budgets for Facebook Advertisements. I have been asked to analyze and measure how an 8.5% decrease in advertiser budgets would impact the prices paid by Facebook advertisers. In other words, I have been asked to measure the difference in the prices paid by Facebook advertisement purchasers between the as-is world (where Facebook provides the Potential Reach metric to advertisers) and the but-for world (where Facebook does not provide the Potential Reach metric to advertisers, and advertiser budgets thus decrease by 8.5%).

[3] Expert Report of Dr. Greg Allenby.

15. *Third*, I have been asked to opine on whether the price differences measured between the but-for and as-is worlds would affect advertisers who would not decrease their budgets in the but-for world (where Facebook does not disseminate then Conjoint-Tested Potential Reach Misrepresentations or Facebook does not provide the Potential Reach metric to advertisers).

16. The following is a summary of the opinions that I render in this matter:

17. Based on my expertise in auction and mechanism design and my review of the discovery in this litigation, I simulated the impact of changes in advertiser budgets for Facebook Advertisements on the prices paid by Facebook advertisers ("Facebook Auction Simulation").

18. *First*, based on the Facebook Auction Simulation, an 8.5% decrease in advertiser budgets for Facebook Advertisements decreases prices for Facebook Advertisements by 8.9%. Thus, assuming that removing the Potential Reach metric would cause an 8.5% decrease in advertiser budgets for Facebook Advertisements, it would also decrease the prices paid for Facebook Advertisements by 8.9%.

19. *Second*, based on the Facebook Auction Simulation, in the but-for world without the shift in budget allocations caused by the Conjoint-Tested Potential Reach Misrepresentations, Facebook Advertisement purchasers would have paid prices that were 3.4% lower than in the as-is world with the Conjoint-Tested Potential Reach Misrepresentations.

20. *Third*, the price differences measured between the but-for and as-is worlds would affect advertisers who would not decrease their budgets in the but-for world (in which Facebook does

not provide the Potential Reach metric to advertisers or Facebook does not disseminate the Conjoint-Tested Potential Reach Misrepresentations). The price decreases of 8.9% and 3.4% respectively apply to all Facebook Advertisement purchasers.

III. Materials Relied Upon

21. In addition to my expertise in algorithmic game theory and auction design, I have reviewed documents produced by Facebook pertaining to their auction pricing system. A full list of the materials that I have relied upon in this matter is attached as **Exhibit 2**.

22. I also attended the deposition of Dr. Chinmay Karande via Zoom on September 18, 2020. It is my understanding that Dr. Karande was Facebook's designated witness regarding "Facebook's methods for determining Facebook Advertisement prices, including Facebook's Ad Auction and the timeline of any substantial modifications made to Facebook's Ad Auction."[4]

23. I also have reviewed the Expert Report of Greg Allenby.

IV. Opinions

A. Background on Vickrey-Clarke-Groves (VCG) Auctions

24. An auction is a mechanism that accepts bids from bidders and decides who gets what and at what price.

[4] Deposition Notice (Plaintiffs' Deposition Exhibit 120)

25. In a first-price auction, the selling price is the bid of the winner.[5]

26. A second-price auction (also known as a Vickrey auction) for a single item awards the item to the highest bidder and charges that bidder the highest bid by the competition (i.e., the second-highest bid overall). Thus, the price charged to the winner does not depend on its own bid, only on others' bids --- on the demand (i.e., willingness to pay) from others.[6] The two main benefits of a second-price auction are: (i) it is relatively easy for bidders to decide what to bid (as bidding your maximum willingness to pay is always in your own best interest); and (ii) assuming bidders do bid their maximum willingness to pay, the auction's outcome is economically efficient, with the item awarded to the bidder with the highest value for it.

27. A Vickrey-Clarke-Groves (VCG) auction generalizes the second-price auction to more complex settings, such as auctions for multiple items (e.g., multiple ad slots on the same Web page).[7] It has the same key properties as a second-price auction: prices depend on others' bids only and not on the winner's bid; the greater the demand from the other bidders, the larger the price; it is always optimal for a bidder to bid its maximum willingness to pay; and assuming all bidders do so, the outcome of the auction is economically efficient.

[5] Roughgarden, Tim. Algorithmic Game Theory. Communications of the ACM, July 2010, Vol. 53 No. 7, Pages 78-86. https://cacm.acm.org/magazines/2010/7/95063-algorithmic-game-theory/fulltext

[6] Roughgarden, T., *Twenty Lectures on Algorithmic Game Theory*, Cambridge University Press, 2016.

[7] Roughgarden, T., *Twenty Lectures on Algorithmic Game Theory*, Cambridge University Press, 2016.

B. Facebook's VCG Advertisement Auction

28. Since August 2014, Facebook Advertisements have been priced one of two ways: (1) through an ad auction system or (2) through Reach and Frequency buying.[8] [redacted]

29. [redacted].”[11]

30. Like other VCG auctions, prices for Facebook Advertisements are based upon the bids of the other bidders in the auction.[12]

---

[8] Facebook Inc.'s Amended and Supplemental Responses to Interrogatory No. 5, at page 6.

[9] Facebook has produced data showing that approximately [redacted] of advertisement impressions between August 15, 2014 and May 16, 2019 used Reach and Frequency buying. Appendix D to Exhibit Report of Armando Levy.

[10] *See e.g.*, FB-SINGER-00186952 / Plaintiffs' Deposition Exhibit 131, at *55 (“[redacted]); FB-SINGER-00186795 / Plaintiffs' Deposition Exhibit 122, at * 96 ([redacted]).

[11] FB-SINGER-00187088.

[12] *See e.g.*, FB-SINGER-00186795 / Plaintiffs' Deposition Exhibit 122, at * 96 ([redacted]

31. [redacted] [13]

32. Facebook also acknowledges on its public website that one of the factors that may determine your Cost-Per-Impression is "market demand."[14] [redacted]

[redacted] Deposition of Chinmay Karande, at 57:20-59:12.

[13] FB-SINGER-00186888 (emphasis added).

[14] FB-SINGER-00089483 / Plaintiffs' Deposition 128.

[15] Facebook Inc.'s Amended and Supplemental Responses to Interrogatory No. 5, at page 7.

33. [redacted].[17]

34. [redacted].[20]

35. [redacted]

[16] Facebook Inc.'s Amended and Supplemental Responses to Interrogatory No. 5, at page 7.

[17] Deposition of Chinmay Karande, at 38:15-39:20.

[18] Deposition of Chinmay Karande, at 105:5-8.

[19] Deposition of Chinmay Karande, at 150:6-8.

[20] Deposition of Chinmay Karande, at 154:3-8.

[redacted]

36. I considered whether Facebook had made substantial modifications to its auction since August 2014. [redacted].[25]

37. I also considered how Reach and Frequency advertisements should be treated in the Facebook Auction Simulation. The pricing for Reach and Frequency is determined based upon the same factors as advertisements purchased through the auction, including market demand[26] [redacted]

---

[21] FB-SINGER-00187518, at *19 / Plaintiffs' Deposition Exhibit 124; Deposition of Chinmay Karande, at 37:1-12.

[22] "CPM" refers to cost per 1,000 impressions. Plaintiffs' Deposition Exhibit 126.

[23] FB-SINGER-00187518, at *19 / Plaintiffs' Deposition Exhibit 124; Karande Deposition, at 36:18-25.

[24] FB-SINGER-00187567 / Plaintiffs' Deposition Exhibit 129.

[25] Deposition of Chinmay Karande at 72:11-17; 98:3-99:3.

[26] FB-SINGER-00089484 / Plaintiffs' Deposition Exhibit 127; Deposition of Chinmay Karande at 45:6-47:13.

[redacted].[27] Because Reach and Frequency ad pricing is determined by the same factors as auction pricing, I did not distinguish between regular ads and Reach and Frequency ads in the Facebook Auction Simulation.

C. <u>Facebook Auction Simulation</u>

1. Parts

38. Based on my expertise in auction and mechanism design and my review of the discovery in this litigation, I simulated the impact of changes in advertiser demand for Facebook Advertisements on the prices paid by Facebook advertisers ("Facebook Auction Simulation").

39. From years of teaching and research, I have experience designing and supervising auction simulations. For example, many assignments in courses that I've designed lead students through Monte Carlo simulations.

40. Auction simulations are routinely used to predict auction outcomes. For example, the designers of the 2016--2017 FCC Spectrum Auction used repeated simulations to evaluate the probable outcomes of different design decisions.[28] Auction simulations have also been used to

[27] Deposition of Chinmay Karande at 47:2-6.

[28] Neil Newman, Kevin Leyton-Brown, Paul Milgrom, and Ilya Segal, "Incentive Auction Design Alternatives: A Simulation Study," *Proceedings of the ACM Conference on Economics and Computation*, pages 603—604, 2020.

explore counterfactual outcomes in online advertising auctions.[29]

41. The simulation of Facebook's auction has four logically distinct parts.

42. First, the "single auction part" simulates Facebook's Vickrey-Clarke-Groves auction, which selects winners for advertising opportunities. This part simulates how multiple advertisements compete to be published on Facebook's platform.

43. Second, the "pacing part" [redacted] The pacing part of the simulation depends on the single auction part, which it invokes for each of its auctions.

44. Third, the "simulator part" computes [redacted]. This part invokes the pacing part after advertisers' budgets have been set.

45. Fourth, the "main part" invokes the simulator code twice – once, based on the budget distribution in the as-is world, and a second time based upon the budget distribution in the but-for world. This main part also computes the difference in prices paid for Facebook Advertisements in the as-is world versus the but-for world.

[29] Susan Athey and Denis Nekipelov, "A Structural Model of Sponsored Search Advertising Auctions," 2011.

46. I have provided the code necessary to replicate all four parts, concurrently with my report.

47. In **Appendix B**, I have provided additional technical information about the parameters that were set in the auction.

Part #1: Single Auction

48. The "single auction part" takes advertiser bids as inputs and determines which advertisements receive an impression and in which slots, and the price paid per impression by each advertiser.

49. To design the single auction part, I began by using a Vickrey-Clarke-Groves auction design, consistent with Facebook's documentation.

50. [redacted]

51. [redacted].”[30]

52. [redacted].”

Part # 2: Pacing

53. As discussed above, Facebook uses a pacing function to smooth advertisers’ spending over the course of the day and determine the advertisers’ paced bids.[31] [redacted].[33]

54. In the Facebook Auction Simulation, the pacing part translates the budget into a bid that can be submitted to the “auction part.”

---

[30] Deposition of Chinmay Karande, at 66:19-67.

[31] Deposition of Chinmay Karande, at 105:5-8.

[32] Deposition of Chinmay Karande, at 150:6-8.

[33] Deposition of Chinmay Karande, at 154:3-8.

55. In designing the pacing module, I relied on internal Facebook documentation and the testimony of Dr. Chinmay Karande.[34]

56. In initializing the pacing module, I relied on the testimony of Dr. Chinmay Karande, who testified that [redacted].[35]

Part # 3: The Simulator

47. This section describes the simulator part, which samples budgets for advertisers and then invokes the pacing part (which in turn invokes the auction part). The input to this part is a distribution over budgets, and the output is a distribution of the number of impressions, the distribution of the total spend, and the distribution of the average cost-per impression.

48. I designed the simulator part to calculate cost-per impression because [redacted].[36] Thus, neither an advertisement's optimization nor what the advertisement is billed need be considered in the Facebook Auction Simulation.

[34] Deposition of Chinmay Karande, 150:6-8; 154:3-8; FB-SINGER-00089483 / Plaintiffs' Deposition Exhibit 128.

[35] Deposition of Chinmay Karande, at 154:3-8.

[36] FB-SINGER-00187518, at *19 / Plaintiffs' Deposition Exhibit 124; Deposition of Chinmay Karande, at 37:1-12.

49. Organic bidders are also represented in the single auction part and hence in the simulator part. As a result, the Facebook Auction Simulation considers the effect on the supply of paid Facebook advertisement slots due to changes in advertiser budgets in the but-for world.

Part # 4: The Main Part

50. The "main part" does the following:

A. Run the simulator part with the as-is budget distribution (as discussed above in the simulator part).

B. Run the simulator part a second time, using the budget distributions when demand has shifted in the but-for world (this was done separately for (i) the 8.5% decrease in demand when Potential Reach is not provided and (ii) the change in demand measured by Dr. Allenby's conjoint survey).

C. Reports the difference in Facebook Advertisement prices (in cost-per-impression) between the but-for world and the as-is world.

D. Reports the difference in the number of Facebook Advertisement impressions between the but-for world and the as-is world.

D. <u>Facebook Auction Simulation Results</u>

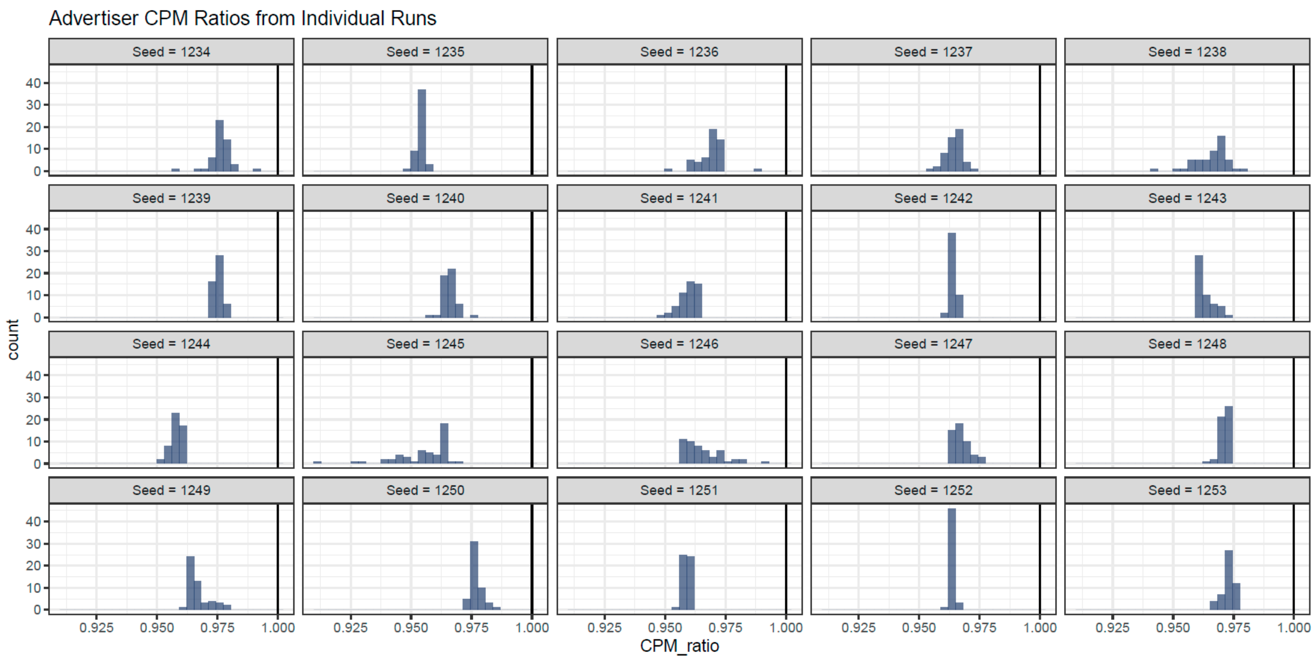
1. Dr. Allenby's Conjoint Study

51. To calculate the price premium due to the Conjoint-Tested Potential Reach Misrepresentations, I ran 20 trials of the simulation with different random seeds and compared outcomes in the as-is and but-for worlds. In the as-is world, the budget distribution is based on the

data provided by Facebook.[37] In the but-for world, this budget distribution is modified according to Dr. Allenby's conjoint results.

52. The results for the differences in the cost-per-impression between the as-is world and the but-for world (where the Conjoint-Tested Potential Reach Misrepresentations are not disseminated) for all the advertisers across the 20 trials are seen in Figure 1. Advertisers are bucketed according to the ratio between their cost-per-impression in the but-for world and their cost-per-impression in the as-is world.

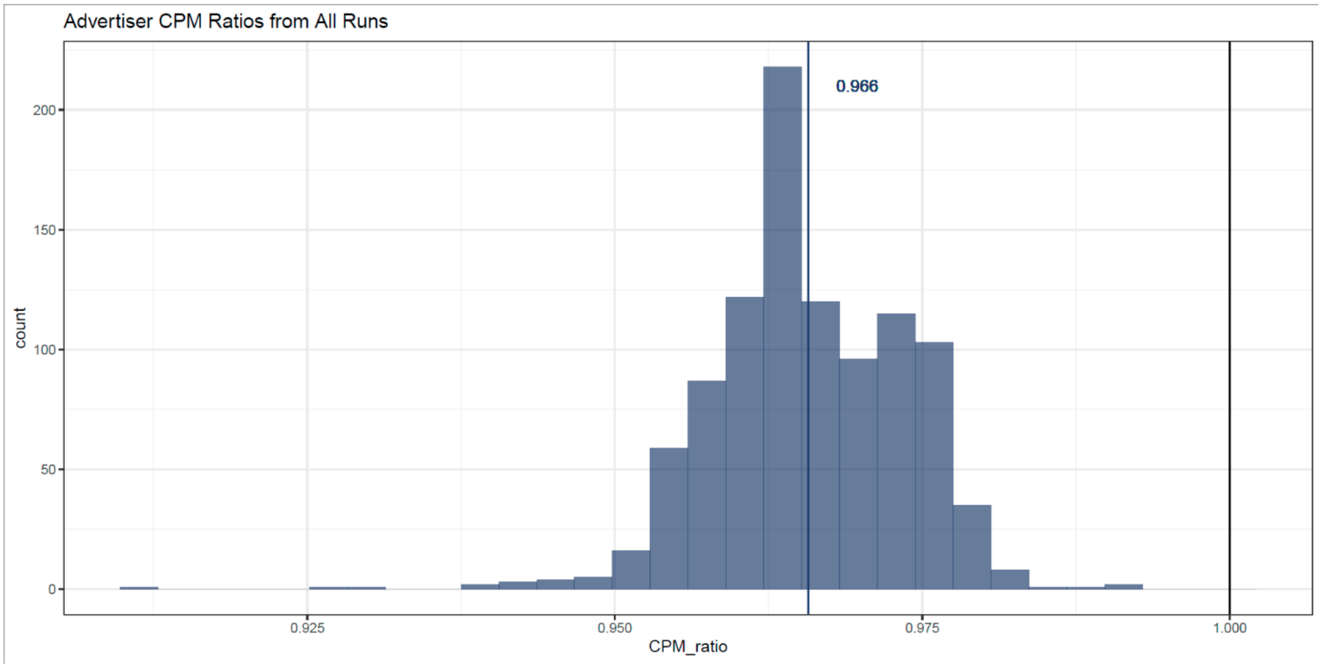
Figure 1: Conjoint VCG Advertiser CPM Ratios (20 Trials)



53. Figure 2 summarizes the results of the 20 different trials in a single histogram.

[37] I provide additional information regarding the budget distributions that I use in Appendix B.

Figure 2: Conjoint VCG Advertiser CPM Ratios (Combined)



54. Based on the 20 random trials, the cost-per-impression in the but-for world (where the Conjoint-Tested Potential Reach Misrepresentations are not disseminated) is 96.6% of the cost-per-impression in the as-is world.

55. Thus, I find that, using Dr. Allenby's conjoint survey to measure the change in budgets caused by the Conjoint-Tested Potential Reach Misrepresentations, Facebook Advertisement purchasers would have paid prices that were 3.4% lower in the but-for world (without the dissemination of the Conjoint-Tested Potential Reach Misrepresentations) than in the as-is world (with the dissemination of the Conjoint-Tested Potential Reach Misrepresentations).

2. Removal of Potential Reach Metric

56. I assumed that not all advertisers would decrease their budgets in the but-for world where Facebook does not provide the Potential Reach metric to advertisers. To set the percentage of advertisers who would change their budgets, I relied on a survey conducted by Facebook of its advertisers.[38] Facebook conducted a survey that showed that 91% percent of advertisers use Potential Reach, and that for 85% of that 91%, it's at least very important that Facebook provides the Potential Reach. Thus, according to the survey, it's at least "very important" to 78% of advertisers that Facebook provides a Potential Reach.

57. To calculate the price premium due to Facebook providing a Potential Reach metric, I ran 20 trials of the simulation with different random seeds and compared outcomes in the as-is and but-for worlds. In the as-is world, the budget distribution is based on the data provided by Facebook.[39] In the but-for world, this budget distribution is modified so that 78% of the advertisers decrease their budgets by 10.9% (for an aggregate budget decrease of 8.5%).

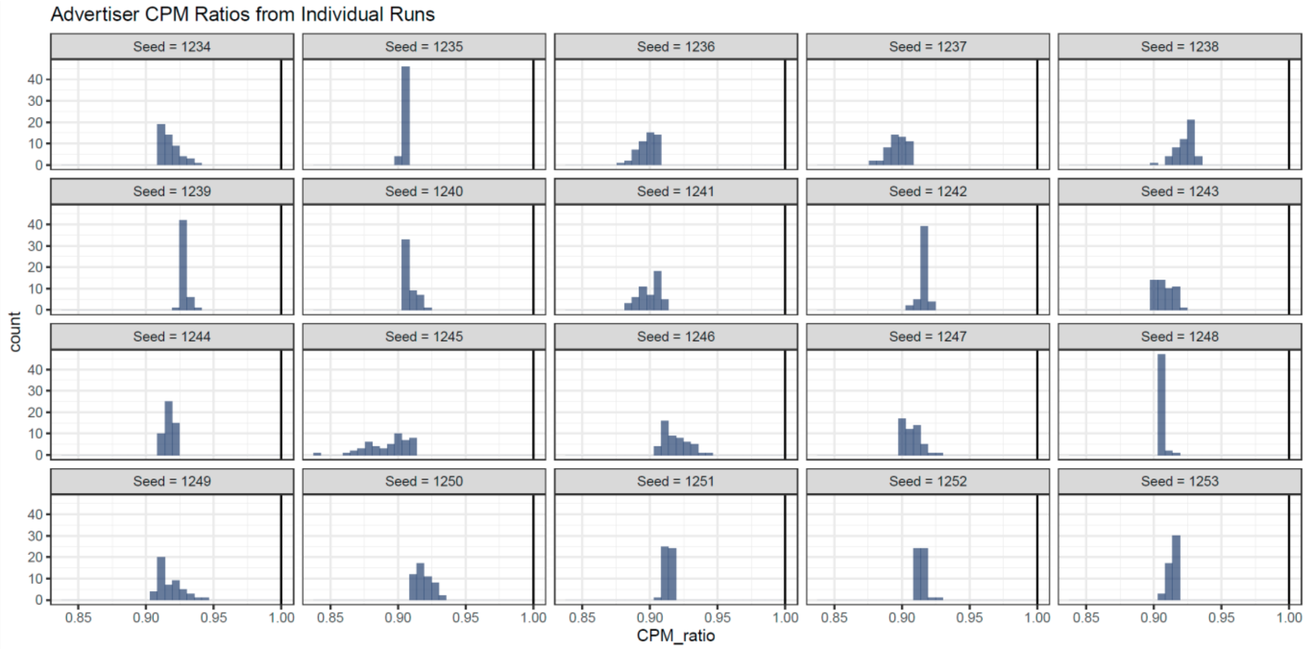
58. The results for the differences in the cost-per-impression between the as-is world and the but-for world (where Facebook removes the Potential Reach metric) for all the advertisers across the 20 trials are seen in Figure 3. Advertisers are bucketed according to the ratio between their cost-per-impression in the but-for world and their cost-per-impression in the as-is world.

---

[38] FB-SINGER-00150228.

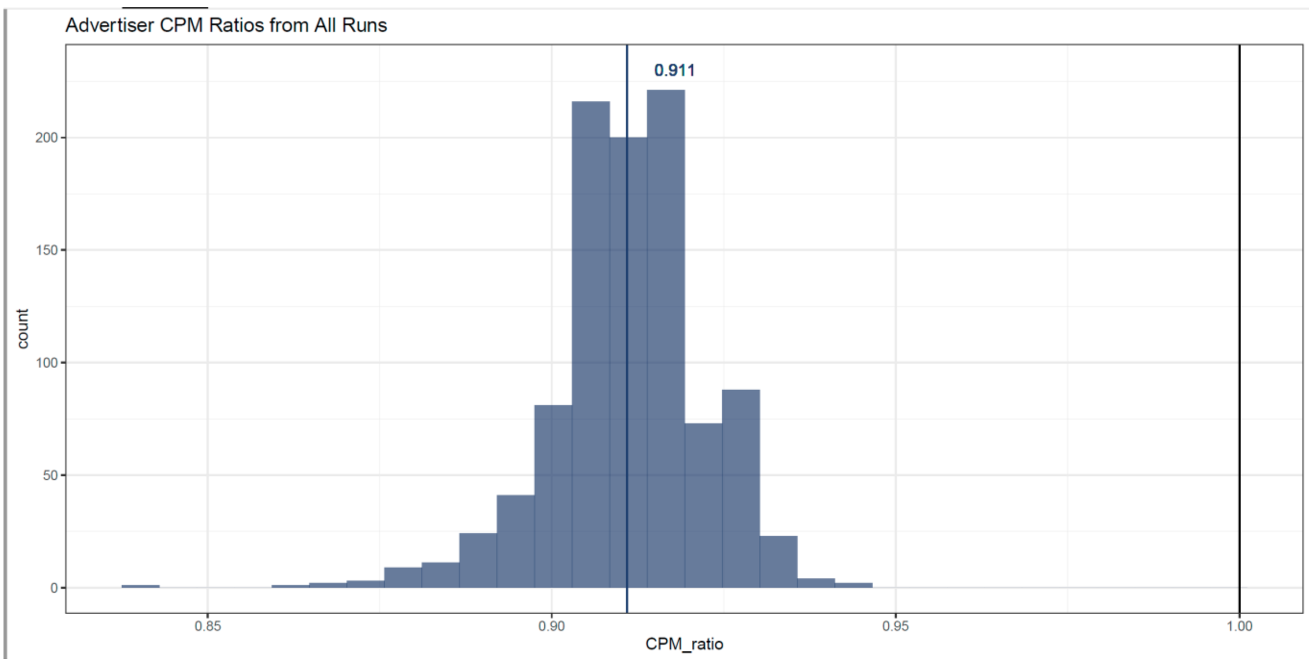
[39] I provide additional information regarding the budget distributions that I use in Appendix B

Figure 3: Removal of Potential Reach - VCG Advertiser CPM Ratios (20 Trials)



59. Figure 4 summarizes the results of the 20 different trials in a single histogram.

Figure 4: Removal of Potential Reach - VCG Advertiser CPM Ratios (Combined)



60. Based on the 20 random trials, the cost-per-impression in the but-for world (where Potential Reach is removed) is 91.1% of the cost-per-impression in the as-is world.

61. Thus, I find that an 8.5% decrease in advertiser budgets for Facebook Advertisements decreases prices for Facebook Advertisements by 8.9%. Thus, assuming that removing the Potential Reach metric would cause an 8.5% decrease in advertiser budgets for Facebook Advertisements, it would also decrease the prices paid for Facebook Advertisements by 8.9%.

3. Impact of Change in Prices on All Advertisers

62. As seen in the figures above, while there is some variance in the amount of the price premium, the cost-per-impression decreases for *all* advertisers in the but-for world where Facebook does not disseminate the Conjoint-Tested Potential Reach Misrepresentations. Although there were respondents in Dr. Allenby's survey who did not decrease their budgets due to the Conjoint-Tested Potential Reach Misrepresentations, those advertisers also pay a lower cost-per-impression in the but-for world where Facebook does not disseminate the Conjoint-Tested Potential Reach Misrepresentations.

63. As seen in the figures above, while there is some variance in the amount of the price premium, the cost-per-impression decreases for *all* advertisers in the but-for world where Facebook removes the Potential Reach. Although I assumed (based on Facebook's survey) that 22% of advertisers would not decrease their budgets due to the removal of the Potential Reach, those advertisers also pay a lower cost-per-impression in the but-for world where Facebook removes the Potential Reach.

64. For those familiar with VCG auctions this is not a surprising result. Like other VCG auctions, prices for Facebook Advertisements are based upon the bids of the other bidders in the auction.[40]

65. Thus, in a VCG auction, the bid of any individual advertiser does not affect the price that that advertiser pays; what matters is the demand generated by all the *other* advertisers in the VCG auction.

66. As Facebook explained in its internal Wiki:

> [redacted]"[41]

67. [redacted]

[40] *See e.g.*, FB-SINGER-00186795 / Plaintiffs' Deposition Exhibit 122, at * 96 [redacted]" Deposition of Chinmay Karande, at 57:20-59:12.

[41] FB-SINGER-00186888 (emphasis added).

E. Sensitivity Analyses

68. I also ran sensitivity analyses to test certain parameters in the Facebook Auction Simulation. The results of the sensitivity analyses are in **Appendix A**.

69. I ran the Facebook Auction Simulation for a GSP auction for both the Conjoint-Tested Potential Reach Misrepresentations and the removal of the Potential Reach. As seen in Figures 5 and 9, the GSP sensitivity analysis results in price premiums of 3.4% and 8.9% respectively, the same price premiums found in the VCG auction.

70. I set the number of advertisement slots to [redacted] based on FB-SINGER-00187567, [redacted]. I also ran sensitivity analyses for a [redacted] for both the Conjoint-Tested Potential Reach Misrepresentations and the removal of the Potential Reach. As seen in Figures 6 and 10, the [redacted] sensitivity analysis results in price premiums of 3.4% and 8.9% respectively, the same price premiums found in the [redacted].

71. I also ran sensitivity analyses for the [redacted] factors at [redacted] and [redacted] for both the Conjoint-Tested Potential Reach Misrepresentations and the removal of the Potential Reach. As seen in Figures 7 and 8, the price premium for the Conjoint-Tested Potential Reach Misrepresentations remains at 3.4%. As seen in Figure 12, the price premium for the removal of Potential Reach remains at 8.9% for a [redacted] positional discount. As seen in Figure 13, the price premium for the removal of the Potential Reach is 8.8% for a [redacted] positional discount, a small change from 8.9%.

72. I also ran a sensitivity analysis specific to the removal of the Potential Reach, where I modified the percentage of advertisers who would decrease their budgets in the but-for world. While this parameter is set at 78% of advertisers, I ran sensitivity analyses where 50% or 100% of advertisers decrease their budgets. As seen in Figure 13, for the sensitivity analysis where 100% of advertisers decrease their budgets, the price premium is 8.5%. As seen in Figure 14, for the sensitivity analysis where 50% of advertisers decrease their budgets, the price premium is 9.1%.

VIII. Conclusions

73. *First*, based on the Facebook Auction Simulation, an 8.5% decrease in advertiser budgets for Facebook Advertisements decreases prices for Facebook Advertisements by 8.9%. Thus, assuming that removing the Potential Reach metric would cause an 8.5% decrease in advertiser budgets for Facebook Advertisements, it would also decrease the prices paid for Facebook Advertisements by 8.9%.

74. *Second*, based on the Facebook Auction Simulation, in the but-for world without the shift in budget allocations caused by the Conjoint-Tested Potential Reach Misrepresentations, Facebook Advertisement purchasers would have paid prices that were 3.4% lower than in the as-is world with the Conjoint-Tested Potential Reach Misrepresentations.

75. *Third*, the price differences measured between the but-for and as-is worlds would affect advertisers who would not decrease their budgets in the but-for world (in which Facebook does not provide the Potential Reach metric to advertisers or Facebook does not disseminate the

Conjoint-Tested Potential Reach Misrepresentations). The price decreases of 8.9% and 3.4% respectively apply to all Facebook Advertisement purchasers.

December 22, 2020

Dr. Timothy Roughgarden

EXHIBIT 1

Tim Roughgarden
Curriculum Vitae

Work Address:
Columbia University
Department of Computer Science
410 Mudd Building, 500 West 120th Street
New York, NY 10027
Home Page: http://www.timroughgarden.org/

Home Address:
165 Christopher Street, Apt #6I
New York, NY
10014
(510) 504-9709
Email: tr@cs.columbia.edu

Education

Ph.D., Computer Science, Cornell University, Ithaca, New York, May 2002.
Thesis: *Selfish Routing*

M.S., Mathematics, Cornell University, Ithaca, New York, May 2002.

M.S., Computer Science, Stanford University, Stanford, California, June 1998.

B.S., Applied Mathematics, Stanford University, Stanford, California, June 1997.

Postdoctoral Employment

Professor, Department of Computer Science, Columbia University, January 2019–present.
Visiting Professor, Department of Mathematics, London School of Economics, September 2017–August 2018.
Professor, Department of Computer Science and (by courtesy) Management Science and Engineering, Stanford University, February 2017–December 2018.
Associate Professor, Department of Computer Science and (by courtesy) Management Science and Engineering, Stanford University, September 2011–January 2017.
Assistant Professor (by courtesy), Department of Management Science and Engineering, Stanford University, September 2004–August 2011.
Postdoctoral Researcher, Computer Science Division, UC Berkeley, August 2003–August 2004.
Postdoctoral Researcher, Department of Computer Science, Cornell University, June 2002–July 2003.

Selected Awards and Honors

FOCS Test of Time Award, 2020
INFORMS Lanchester Prize, 2019
Fellow of the Game Theory Society, 2019
Guggenheim Fellowship, 2017
Stanford Tau Beta Pi Teaching Honor Roll, 2017
Kalai Prize in Game Theory and Computer Science, 2016
Social Choice and Welfare Prize, 2014
EATCS-SIGACT Gödel Prize, 2012
ACM Grace Murray Hopper Award, 2009
Shapley Lecturer, Third World Congress of the Game Theory Society, 2008
Game Theory Society Prize in Game Theory and Computer Science, Honorable Mention, 2008
Presidential Early Career Award for Scientists and Engineers (PECASE), 2007
ONR Young Investigator, 2007–2010
Alfred P. Sloan Fellow, 2006–2008
International Congress of Mathematicians Invited Speaker, 2006

INFORMS Optimization Prize for Young Researchers, 2003
Mathematical Programming Society's Tucker Prize, 2003
ACM Doctoral Dissertation Award, Honorable Mention, 2002
Danny Lewin Best Student Paper Award, STOC 2002

Books and Monographs

1. T. Roughgarden (editor), *Beyond the Worst-Case Analysis of Algorithms*, Cambridge University Press, 2020.
2. T. Roughgarden, *Complexity Theory, Game Theory, and Economics: The Barbados Lectures*, Foundations and Trends in Theoretical Computer Science, Now Publishers, 2020.
3. T. Roughgarden, *Algorithms Illuminated, Part 4: Algorithms for NP-Hard Problems*, Soundlikeyourself Publishing, 2020.
4. T. Roughgarden, *Algorithms Illuminated, Part 3: Greedy Algorithms and Dynamic Programming*, Soundlikeyourself Publishing, 2019.
5. T. Roughgarden, *Algorithms Illuminated, Part 2: Graph Algorithms and Data Structures*, Soundlikeyourself Publishing, 2018.
6. T. Roughgarden, *Algorithms Illuminated, Part 1: The Basics*, Soundlikeyourself Publishing, 2017.
7. T. Roughgarden, *Twenty Lectures on Algorithmic Game Theory*, Cambridge University Press, 2016.
8. T. Roughgarden, *Communication Complexity (for Algorithm Designers)*, Foundations and Trends in Theoretical Computer Science, Now Publishers, 2016.
9. N. Nisan, T. Roughgarden, É. Tardos, and V. V. Vazirani (editors), *Algorithmic Game Theory*, Cambridge University Press, 2007.
10. T. Roughgarden, *Selfish Routing and the Price of Anarchy*, MIT Press, 2005.

Book Chapters

1. T. Roughgarden and C. Seshadhri, "Distribution-Free Models of Social Networks," chapter 28 in *Beyond the Worst-Case Analysis of Algorithms*, T. Roughgarden, editor, Cambridge University Press, pages 606–625, 2020.
2. T. Roughgarden, "Distributional Analysis," chapter 8 in *Beyond the Worst-Case Analysis of Algorithms*, T. Roughgarden, editor, Cambridge University Press, pages 167–188, 2020.
3. T. Roughgarden, "Resource Augmentation," chapter 4 in *Beyond the Worst-Case Analysis of Algorithms*, T. Roughgarden, editor, Cambridge University Press, pages 72–91, 2020.
4. T. Roughgarden, "Introduction (to Beyond Worst-Case Analysis)," chapter 1 in *Beyond the Worst-Case Analysis of Algorithms*, T. Roughgarden, editor, Cambridge University Press, pages 1–23, 2020.
5. T. Roughgarden, "Complexity-Theoretic Barriers in Economics," in *The Future of Economic Design*, J.-F. Laslier, H. Moulin, R. Sanver, and W. S. Zwicker, editors, Springer, 2019.
6. T. Roughgarden, "Routing Games," chapter 18 in *Algorithmic Game Theory*, N. Nisan, T. Roughgarden, É. Tardos, and V. V. Vazirani, editors, Cambridge University Press, pages 461–486, 2007.
7. T. Roughgarden and É. Tardos, "Introduction to the Inefficiency of Equilibria," chapter 17 in *Algorithmic Game Theory*, N. Nisan, T. Roughgarden, É. Tardos, and V. V. Vazirani, editors, Cambridge University Press, pages 443–459, 2007.

Edited Conference Proceedings

1. T. Roughgarden, M. Feldman, and M. Schwarz, editors, *Proceedings of the 16th ACM Conference on Economics and Computation (EC)*, ACM, 2015.

2. T. Roughgarden, editor, *Proceedings of the 2015 Conference on Innovations in Theoretical Computer Science (ITCS)*, ACM, 2015.

3. D. Boneh, T. Roughgarden, and J. Feigenbaum, editors, *Proceedings of the 43rd Annual ACM Symposium on Theory of Computing (STOC)*, ACM, 2013.

4. T. Roughgarden, editor, *Proceedings of the 53rd Annual IEEE Symposium on Foundations of Computer Science (FOCS)*, IEEE, 2012.

5. Y. Shoham, Y. Chen, and T. Roughgarden, editors, *Proceedings of the 12th ACM Conference on Electronic Commerce (EC)*, ACM, 2011.

Journal Publications

1. P. D. Dütting, T. Roughgarden, and I. Talgam-Cohen, "The Complexity of Contracts," submitted to *SIAM Journal on Computing*, 2020.

2. S. Bhattacharya, E. Koutsoupias, J. Kulkarni, S. Leonardi, T. Roughgarden, and X. Xu, "Prior-Free Multi-Unit Auctions with Ordered Bidders," *Theoretical Computer Science*, to appear.

3. R. Niazadeh, T. Roughgarden, and J. R. Wang, "Optimal Algorithms for Continuous Non-monotone Submodular and DR-Submodular Maximization," *Journal of Machine Learning Research*, 21:1–31, June 2020.

4. T. Roughgarden, I. Talgam-Cohen, and Q. Yan, "Robust Auctions for Revenue via Enhanced Competition," *Operations Research*, 68(4):1074–1094, June 2020.

5. R. Gupta and T. Roughgarden, "Data-Driven Algorithm Design," *Communications of the ACM*, 63(6):87–94, June 2020.

6. J. Fox, T. Roughgarden, C. Seshadhri, F. Wei, and N. Wein, "Finding Cliques in Social Networks: A New Distribution-Free Model," *SIAM Journal on Computing*, 49(2):448–464, April 2020.

7. R. Colini-Baldeschi, P. W. Goldberg, B. de Keijzer, S. Leonardi, T. Roughgarden, and S. Turchetta, "Approximately Efficient Two-Sided Combinatorial Auctions," *ACM Transactions on Economics and Computation*, 8(1):Article 4 April 2020.

8. B. Plaut and T. Roughgarden, "Almost Envy-Freeness with General Valuations," *SIAM Journal on Discrete Mathematics*, 34(2):1039–1068, April 2020.

9. B. Plaut and T. Roughgarden, "The Communication Complexity of Discrete Fair Division," *SIAM Journal on Computing*, 49(1):206–243, April 2020.

10. T. Ezra, M. Feldman, T. Roughgarden, and W. Suksompong, "Pricing Multi-Unit Markets," *ACM Transactions on Economic and Computation*, 7(4):Article 20, January 2020.

11. T. Roughgarden and J. R. Wang, "Minimizing Regret with Multiple Reserves," *ACM Transactions on Economic and Computation*, 7(3): Article 17, October 2019.

12. T. Roughgarden and I. Talgam-Cohen, "Approximately Optimal Mechanism Design," *Annual Reviews of Economics*, volume 11, August 2019.

13. T. Roughgarden, "Beyond Worst-Case Analysis," *Communications of the ACM*, 62(3):88–96, March 2019.

14. G. Barmpalias, N. Huang, A. Lewis-Pye, A. Li, X. Li, Y. Pan, and T. Roughgarden, "The Idemetric Property: When Most Distances Are (Almost) the Same," *Proceedings of the Royal Society of London*, 475(2222), February 2019.

15. P. Gopalan, N. Nisan, and T. Roughgarden, "Public Projects, Boolean Functions, and the Borders of Border's Theorem," *ACM Transactions on Economic and Computation*, 6(3-4): Article 18, November 2018.

16. T. Roughgarden, S. Vassilvitskii, and J. R. Wang, "Shuffles and Circuits (On Lower Bounds for Modern Parallel Computation)," *Journal of the ACM*, 65(6):Article 41, November 2018.

17. Z. Huang, Y. Mansour, and T. Roughgarden, "Making the Most of Your Samples," *SIAM Journal on Computing*, 47(3):651–674, May 2018.

18. S. Dobzinski, A. Mehta, T. Roughgarden, and M. Sundararajan, "Is Shapley Cost Sharing Optimal?," *Games and Economic Behavior*, 108(1):130–138, March 2018.

19. P. D. Dütting, V. Gkatzelis, and T. Roughgarden, "The Power of Deferred Heuristic Auctions," *Mathematics of Operations Research*, 42(4):897–914, November 2017.

20. P. D. Dütting, T. Roughgarden, and I. Talgam-Cohen, "Modularity and Greed in Double Auctions," *Games and Economic Behavior*, 105:59–83, September 2017.

21. R. Gupta and T. Roughgarden, "A PAC Approach to Application-Specific Algorithm Selection," *SIAM Journal on Computing*, 46(3):992–1017, June 2017.

22. T. Roughgarden, V. Syrgkanis, and É. Tardos, "The Price of Anarchy in Auctions," *Journal of Artificial Intelligence Research*, 59:59–101, May 2017.

23. Y. Chen, A. Ghosh, M. Kearns, T. Roughgarden, and J. Wortman Vaughan, "Mathematical Foundations for Social Computing," *Communications of the ACM*, 59(12):102–108, December 2016.

24. J. Hsu, Z. Huang, A. Roth, T. Roughgarden, and Z. S. Wu, "Private Matchings and Allocations," *SIAM Journal on Computing*, 45(6):1953–1984, November 2016.

25. V. Gkatzelis, K. Kollias, and T. Roughgarden, "Optimal Cost-Sharing in General Resource Selection Games," *Operations Research*, 64(6):1230–1238, November 2016.

26. S. Dughmi, T. Roughgarden, and Q. Yan, "Optimal Mechanisms for Combinatorial Auctions and Combinatorial Public Projects via Convex Rounding," *Journal of the ACM*, 63(4):Article 30, September 2016.

27. T. Roughgarden and I. Talgam-Cohen, "Optimal and Near-Optimal Mechanism Design with Interdependent Values," *ACM Transactions on Economics and Computation*, 4(3):Article 18, June 2016.

28. R. Gupta, T. Roughgarden, and C. Seshadhri, "Decompositions of Triangle-Dense Graphs," *SIAM Journal on Computing*, 45(2):197–215, March 2016.

29. T. Roughgarden and O. Schrijvers, "Network Cost-Sharing without Anonymity," *ACM Transactions on Economics and Computation*, 4(2):Article 8, February 2016.

30. T. Roughgarden, "Intrinsic Robustness of the Price of Anarchy," *Journal of the ACM*, 62(5):Article 32, November 2015.

31. K. Bhawalkar, J. Kleinberg, K. Lewi, T. Roughgarden, and A. Sharma, "Preventing Unraveling in Social Networks: The Anchored k-Core Problem," *SIAM Journal on Discrete Mathematics*, 29(3):1452–1475, August 2015.

32. K. Kollias and T. Roughgarden, "Restoring Pure Equilibria to Weighted Congestion Games," *ACM Transactions on Economics and Computation*, 3(4):Article 21, July 2015.

33. P. Dhangwatnotai, T. Roughgarden, and Q. Yan, "Revenue Maximization with a Single Sample," *Games and Economic Behavior*, 91:318–333, May 2015.

34. T. Roughgarden, "The Price of Anarchy in Games of Incomplete Information," *ACM Transactions on Economics and Computation*, 3(1):Article 6, March 2015.

35. T. Roughgarden and F. Schoppmann, "Local Smoothness and the Price of Anarchy in Atomic Splittable Congestion Games," *Journal of Economic Theory*, 156:317–342, March 2015.

36. T. Roughgarden, "Approximately Optimal Mechanism Design: Motivation, Examples, and Lessons Learned," *SIGecom Exchanges*, pages 4–20, December 2014.

37. K. Bhawalkar, M. Gairing, and T. Roughgarden, "Weighted Congestion Games: Price of Anarchy, Universal Worst-Case Examples, and Tightness," *ACM Transactions on Economics and Computation*, 2(4):Article 14, October 2014.

38. J. R. Marden and T. Roughgarden, "Generalized Efficiency Bounds In Distributed Resource Allocation," *IEEE Transactions on Automatic Control*, 59(3):571–584, March 2014.

39. S. Dughmi and T. Roughgarden, "Black-Box Randomized Reductions in Algorithmic Mechanism Design," *SIAM Journal on Computing*, 43(1):312–336, February 2014.

40. S. Dughmi, T. Roughgarden, and M. Sundararajan, "Revenue Submodularity," *Theory of Computing*, 8:95–119, December 2012.

41. A. Ghosh, T. Roughgarden, and M. Sundararajan, "Universally Utility-Maximizing Privacy Mechanisms," *SIAM Journal on Computing*, 41(6):1673–1693, December 2012.

42. R. Cole, Y. Dodis, and T. Roughgarden, "Bottleneck Links, Variable Demand, and the Tragedy of the Commons," *Networks*, 60(3):194–203, October 2012.

43. T. Roughgarden, "Intrinsic Robustness of the Price of Anarchy," *Communications of the ACM*, 55(7):116–123, July 2012.

    [Version of conference paper 69 for CACM "Research Highlights" column.]

44. H. Lin, T. Roughgarden, É. Tardos, and A. Walkover, "Stronger Bounds on Braess's Paradox and the Maximum Latency of Selfish Routing," *SIAM Journal on Discrete Mathematics*, 25(4):1667–1686, December 2011.

45. P. Dhangwatnotai, S. Dobzinski, S. Dughmi, and T. Roughgarden,, "Truthful Approximation Schemes for Single-Parameter Agents," *SIAM Journal on Computing*, 40(3):915–933, June 2011.

46. R. Krauthgamer and T. Roughgarden, "Metric Clustering via Consistent Labeling," *Theory of Computing*, 7:49-74, March 2011.

47. G. Valiant and T. Roughgarden, "Braess's Paradox in Large Random Graphs," *Random Structures and Algorithms*, 37(4):495–515, December 2010.

48. D. Mosk-Aoyama, T. Roughgarden, and D. Shah, "Fully Distributed Algorithms for Convex Optimization," *SIAM Journal on Optimization*, 20(6):3260–3279, October 2010.

49. T. Roughgarden, "Algorithmic Game Theory," *Communications of the ACM*, 53(7):78–86, July 2010.

50. H. Chen, T. Roughgarden, and G. Valiant, "Designing Network Protocols for Good Equilibria," *SIAM Journal on Computing*, 39(5):1799–1832, January 2010.

51. T. Roughgarden, "Computing Equilibria: A Computational Complexity Perspective," *Economic Theory*, 42(1):193–236, January 2010.

52. A. Mehta, T. Roughgarden, and M. Sundararajan, "Beyond Moulin Mechanisms," *Games and Economic Behavior*, 67(1):125–155, September 2009.

53. H. Chen and T. Roughgarden, "Network Design with Weighted Players," *Theory of Computing Systems*, 45(2):302-324, August 2009.

54. T. Roughgarden and M. Sundararajan, "Quantifying Inefficiency in Cost-Sharing Mechanisms," *Journal of the ACM*, 56(4), Article 23, June 2009.

55. E. Anshelevich, A. Dasgupta, J. Kleinberg, É. Tardos, T. Wexler, and T. Roughgarden, "The Price of Stability for Network Design with Fair Cost Allocation," *SIAM Journal on Computing*, 38(4):1602–1623, November 2008.

56. C. H. Papadimitriou and T. Roughgarden, "Computing Correlated Equilibria in Multi-Player Games," *Journal of the ACM*, 55(3), Article 14, July 2008.

57. M. Haviv and T. Roughgarden, "The Price of Anarchy in an Exponential Multi-Server," *Operations Research Letters*, 35(4):421–426, July 2007.

58. A. Gupta, A. Kumar, M. Pál, and T. Roughgarden, "Approximation via Cost-Sharing: Simpler and Better Approximation Algorithms for Network Design," *Journal of the ACM*, 54(3), Article 11, June 2007.

59. T. Roughgarden, "Selfish Routing and the Price of Anarchy," *OPTIMA*, 74:1-15, May 2007.

60. T. Roughgarden, "On the Severity of Braess's Paradox: Designing Networks for Selfish Users Is Hard," *Journal of Computer and System Sciences*, 72(5):922–953, August 2006.

61. R. Cole, Y. Dodis, and T. Roughgarden, "How Much Can Taxes Help Selfish Routing?," *Journal of Computer and System Sciences*, 72(3):444–467, May 2006.

62. M. Saha, G. Sanchez-Ante, T. Roughgarden, and J.C. Latombe, "Planning Tours of Robotic Arms Among Partitioned Goals," *International Journal of Robotics Research*, 25(3):207–223, March 1 2006.

63. M. Enachescu, Y. Ganjali, A. Goel, N. McKeown, and T. Roughgarden, "Routers with Very Small Buffers," *ACM Computer Communication Review*, 35(3):83–90, July 2005.

64. F. A. Chudak, T. Roughgarden, and D. P. Williamson, "Approximate k-MSTs and k-Steiner Trees via the Primal-Dual Method and Lagrangean Relaxation," *Mathematical Programming*, 100(2):411–421, June 2004.

65. T. Roughgarden, "Stackelberg Scheduling Strategies," *SIAM Journal on Computing*, 33(2):332–350, June 2004.

66. T. Roughgarden and É. Tardos, "Bounding the Inefficiency of Equilibria in Nonatomic Congestion Games," *Games and Economic Behavior*, 47(2):389–403, May 2004.

67. T. Roughgarden, "The Price of Anarchy Is Independent of the Network Topology," *Journal of Computer and System Sciences*, 67(2):341–364, September 2003.

68. A. J. Hoffman, K. Jenkins, and T. Roughgarden, "On A Game in Directed Graphs," *Information Processing Letters*, 83(1):13–16, 16 July 2002.

69. T. Roughgarden and É. Tardos, "How Bad Is Selfish Routing?," *Journal of the ACM*, 49(2):236–259, March 2002.

Publications in Refereed Conference Proceedings

1. A. Lewis-Pye and T. Roughgarden, "A General Framework for the Security Analysis of Blockchain Protocols," submitted to the *40th Annual International Conference on the Theory and Applications of Cryptographic Techniques (EUROCRYPT)*, May 2021.

2. T. Roughgarden and C. Shinkelman, "Ignore the Extra Zeroes: Variance-Optimal Mining Pools," submitted to the *25th International Conference on Financial Cryptography (FC)*, February 2021.

3. N. Haghtalab and T. Roughgarden and A. Shetty, "Smoothed Analysis of Online and Private Learning," *33rd Annual Conference on Neural Information Processing Systems (NeurIPS)*, 2020, to appear.

4. P. D. Dütting, T. Roughgarden, and I. Talgam-Cohen, "The Complexity of Contracts," *30th Annual Symposium on Discrete Algorithms (SODA)*, pages 2688–2707, 2020.

5. X. Chen and C. H. Papadimitriou and T. Roughgarden, "An Axiomatic Approach to Block Rewards," *First ACM Conference on Alternative Financial Technologies (AFT)*, pages 124–131, 2019.

6. V. Chatziafratis, T. Roughgarden, and J. R. Wang, "On the Computational Power of Online Gradient Descent," *32nd Annual Conference on Learning Theory (COLT)*, pages 624–662, 2019.

7. P. D. Dütting, T. Roughgarden, and I. Talgam-Cohen, "Simple versus Optimal Contracts," *18th Annual ACM Conference on Economics and Computation (EC)*, pages 369–387, 2019.

8. B. Plaut and T. Roughgarden, "The Communication Complexity of Discrete Fair Division," *29th Annual Symposium on Discrete Algorithms (SODA)*, pages 2014–2033, 2019.

9. T. Ezra, M. Feldman, T. Roughgarden, and W. Suksompong, "Pricing Multi-Unit Markets," *14th Conference on Web and Internet Economics (WINE)*, pages 140–153, 2018.

10. R. Niazadeh, T. Roughgarden, and J. R. Wang, "Optimal Algorithms for Continuous Non-monotone Submodular and DR-Submodular Maximization," *31st Annual Conference on Neural Information Processing Systems (NeurIPS)*, pages 9617–9627, 2018.

11. T. Roughgarden and J. Wang, "An Optimal Learning Algorithm for Online Unconstrained Submodular Maximization," *31st Annual Conference on Learning Theory (COLT)*, pages 1307–1325, 2018.

12. J. Fox, T. Roughgarden, C. Seshadhri, F. Wei, and N. Wein, "Finding Cliques in Social Networks: A New Distribution-Free Model," *46th International Symposium on Automata, Languages, and Programming (ICALP)*, Article 55, 2018.

13. B. Plaut and T. Roughgarden, "Almost Envy-Freeness with General Valuations," *28th Annual Symposium on Discrete Algorithms (SODA)*, pages 2584–2603, 2018.

14. T. Roughgarden and O. Schrijvers, "Online Prediction with Selfish Experts," *30th Annual Conference on Neural Information Processing Systems (NIPS)*, pages 1300–1310, 2017.

15. V. Chatziafratis, T. Roughgarden, and J. Vondrak, "Stability and Recovery for Independence Systems," *25th Annual European Symposium on Algorithms (ESA)*, 2017.

16. T. Roughgarden, I. Talgam-Cohen, and J. Vondrak, "When Are Welfare Guarantees Robust?," *20th International Workshop on Approximation Algorithms for Combinatorial Optimization Problems (APPROX)*, pages 1–22, 2017.

17. R. Colini-Baldeschi, P. W. Goldberg, B. de Keijzer, S. Leonardi, T. Roughgarden, and S. Turchetta, "Approximately Efficient Two-Sided Combinatorial Auctions," *18th Annual ACM Conference on Economics and Computation (EC)*, pages 591–608, 2017.

18. V. Gkatzelis, E. Markakis, and T. Roughgarden, "Deferred-Acceptance Auctions for Multiple Levels of Service," *18th Annual ACM Conference on Economics and Computation (EC)*, pages 21–38, 2017.

19. T. Roughgarden and O. Weinstein, "On the Communication Complexity of Approximate Fixed Points," *57th Annual Symposium on Foundations of Computer Science (FOCS)*, pages 229–238, 2016.

20. T. Roughgarden and J. R. Wang, "On the Complexity of the k-Means Method," *24th Annual European Symposium on Algorithms (ESA)*, pages 78:1–78:14, 2016.

21. T. Roughgarden and J. R. Wang, "Minimizing Regret with Multiple Reserves," *17th Annual ACM Conference on Economics and Computation (EC)*, pages 601–616, 2016.

22. T. Roughgarden and O. Schrijvers, "Ironing in the Dark," *17th Annual ACM Conference on Economics and Computation (EC)*, pages 1–18, 2016.

23. T. Roughgarden, S. Vassilvitskii, and J. R. Wang, "Shuffles and Circuits (On Lower Bounds for Modern Parallel Computation)," *28th ACM Symposium on Parallelism in Algorithms and Architectures (SPAA)*, pages 1–12, 2016. **Best Paper Award.**

24. J. Morgenstern and T. Roughgarden, "Learning Simple Auctions," *29th Annual Conference on Learning Theory (COLT)*, pages 1298–1318, 2016.

25. M. Feldman, N. Immorlica, B. Lucier, T. Roughgarden, and V. Syrgkanis, "The Price of Anarchy in Large Games," *49th Annual ACM Symposium on Theory of Computing (STOC)*, pages 963–976, 2016.

26. O. Schrijvers, J. Bonneau, D. Boneh, and T. Roughgarden, "Incentive Compatibility of Bitcoin Mining Pool Reward Functions," *20th International Conference on Financial Cryptography (FC)*, 2016.

27. R. Gupta and T. Roughgarden, "A PAC Approach to Application-Specific Algorithm Selection," *7th Conference on Innovations in Theoretical Computer Science (ITCS)*, pages 123–134, 2016.

28. J. Morgenstern and T. Roughgarden, "The Pseudo-Dimension of Near-Optimal Auctions," *28th Annual Conference on Neural Information Processing Systems (NIPS)*, pages 136–144, 2015.

29. A. Globerson, T. Roughgarden, D. Sontag, and C. Yildirim, "How Hard Is Inference for Structured Prediction?," *32nd International Conference on Machine Learning (ICML)*, pages 2181–2190, 2015.

30. P. Gopalan, N. Nisan, and T. Roughgarden, "Public Projects, Boolean Functions, and the Borders of Border's Theorem," *16th Annual ACM Conference on Economics and Computation (EC)*, page 395, 2015.

31. Z. Huang, Y. Mansour, and T. Roughgarden, "Making the Most of Your Samples," *16th Annual ACM Conference on Economics and Computation (EC)*, pages 45–60, 2015.

32. T. Roughgarden and I. Talgam-Cohen, "Why Prices Need Algorithms," *16th Annual ACM Conference on Economics and Computation (EC)*, pages 19–36, 2015. **(Talgam-Cohen was awarded the Best Student Paper Prize for this paper.)**

33. V. Gkatzelis, K. Kollias, and T. Roughgarden, "Optimal Cost-Sharing in Weighted Congestion Games," *10th Conference on Web and Internet Economics (WINE)*, pages 72–88, 2014.

34. T. Roughgarden, "Barriers to Near-Optimal Equilibria," *55th Annual Symposium on Foundations of Computer Science (FOCS)*, pages 71–80, 2014.

35. T. Roughgarden and O. Schrijvers, "Network Cost-Sharing without Anonymity," *7th International Symposium on Algorithmic Game Theory (SAGT)*, pages 134–145, 2014.

36. J. Hsu, A. Roth, T. Roughgarden, and J. Ullman, "Privately Solving Linear Programs," *42nd International Symposium on Automata, Languages, and Programming (ICALP)*, pages 612–624, 2014.

37. P. D. Dütting, T. Roughgarden, and I. Talgam-Cohen, "Incentives and Greed in Double Auctions," *15th Annual ACM Conference on Electronic Commerce (EC)*, pages 241–258, 2014.

38. P. D. Dütting, V. Gkatzelis, and T. Roughgarden, "The Power of Deferred Heuristic Auctions," *15th Annual ACM Conference on Electronic Commerce (EC)*, pages 187–204, 2014.

39. R. Cole and T. Roughgarden, "The Sample Complexity of Revenue Maximization," *46th Annual ACM Symposium on Theory of Computing (STOC)*, pages 243–252, 2014.

40. J. Hsu, Z. Huang, A. Roth, T. Roughgarden, and Z. S. Wu, "Private Matchings and Allocations," *46th Annual ACM Symposium on Theory of Computing (STOC)*, pages 21–30, 2014.

41. R. Gupta, T. Roughgarden, and C. Seshadhri, "Decompositions of Triangle-Dense Graphs," *5th Conference on Innovations in Theoretical Computer Science (ITCS)*, pages 471–482, 2014.

42. M. Kearns and T. Roughgarden, "Marginals-to-Models Reducibility," *26th Annual Conference on Neural Information Processing Systems (NIPS)*, pages 1043–1051, 2013.

43. T. Roughgarden and I. Talgam-Cohen, "Optimal and Near-Optimal Mechanism Design with Interdependent Values," *14th Annual ACM Conference on Electronic Commerce (EC)*, pages 767–784, 2013.

44. S. Bhattacharya, E. Koutsoupias, J. Kulkarni, S. Leonardi, T. Roughgarden, and X. Xu, "Near-Optimal Multi-Unit Auctions with Ordered Bidders," *14th Annual ACM Conference on Electronic Commerce (EC)*, pages 91–102, 2013.

45. K. Bhawalkar and T. Roughgarden, "Simultaneous Single-Item Auctions," *8th International Workshop on Internet & Network Economics (WINE)*, pages 338–350, 2012.

46. K. Bhawalkar, J. Kleinberg, K. Lewi, T. Roughgarden, and A. Sharma, "Preventing Unraveling in Social Networks: The Anchored k-Core Problem," *40th International Symposium on Automata, Languages, and Programming (ICALP)*, pages 440–451, 2012.

47. T. Roughgarden and É. Tardos, "Do Externalities Degrade GSP's Efficiency?," *8th Ad Auctions Workshop*, 2012.

48. T. Roughgarden, "The Price of Anarchy in Games of Incomplete Information," *13th Annual ACM Conference on Electronic Commerce (EC)*, pages 862–879, 2012.

49. T. Roughgarden, I. Talgam-Cohen, and Q. Yan, "Supply-Limiting Mechanisms," *13th Annual ACM Conference on Electronic Commerce (EC)*, pages 844–861, 2012.

50. I. Abraham, M. Babaioff, S. Dughmi, and T. Roughgarden, "Combinatorial Auctions with Restricted Complements," *13th Annual ACM Conference on Electronic Commerce (EC)*, pages 3–16, 2012.

51. S. Leonardi and T. Roughgarden, "Prior-Free Auctions with Ordered Bidders," *44th Annual ACM Symposium on Theory of Computing (STOC)*, pages 427–434, 2012.

52. A. Badanidiyuru, S. Dobzinski, H. Fu, R. D. Kleinberg, N. Nisan, and T. Roughgarden, "Sketching Valuation Functions," *22nd Annual Symposium on Discrete Algorithms (SODA)*, pages 1025–1035, 2012.

53. R. Johari, U. Nadav, and T. Roughgarden, "Uncoupled Potentials for Proportional Allocation Markets," *50th IEEE Conference on Decision and Control (CDC)*, pages 4479–4484, 2011.

54. R. Kumar, J. O. Talton, S. Ahmad, T. Roughgarden, and S. R. Klemmer, "Flexible Tree Matching," *22nd International Joint Conference on Artificial Intelligence (IJCAI)*, pages 2674–2679, 2011.

55. K. Kollias and T. Roughgarden, "Restoring Pure Equilibria to Weighted Congestion Games," *38th International Symposium on Automata, Languages, and Programming (ICALP)*, pages 539–551, 2011.

56. S. Dughmi, T. Roughgarden, and Q. Yan, "From Convex Optimization to Randomized Mechanisms: Toward Optimal Combinatorial Auctions with Submodular Bidders," *43rd Annual ACM Symposium on Theory of Computing (STOC)*, pages 149–158, 2011.

57. K. Bhawalkar and T. Roughgarden, "Welfare Guarantees for Combinatorial Auctions with Item Bidding," *21st Annual Symposium on Discrete Algorithms (SODA)*, pages 700–709, 2011.

58. T. Roughgarden and F. Schoppmann, "Local Smoothness and the Price of Anarchy in Atomic Splittable Congestion Games," *21st Annual Symposium on Discrete Algorithms (SODA)*, pages 255–267, 2011.

59. U. Nadav and T. Roughgarden, "The Limits of Smoothness: A Primal-Dual Framework for Price of Anarchy Bounds," *6th International Workshop on Internet & Network Economics (WINE)*, pages 319–326, 2010.

60. J. R. Marden and T. Roughgarden, "Generalized Efficiency Bounds In Distributed Resource Allocation," *49th IEEE Conference on Decision and Control (CDC)*, pages 2233–2238, 2010.

61. S. Dughmi and T. Roughgarden, "Black-Box Randomized Reductions in Algorithmic Mechanism Design," *51st Annual Symposium on Foundations of Computer Science (FOCS)*, pages 775–784, 2010.

62. K. Bhawalkar, M. Gairing, and T. Roughgarden, "Weighted Congestion Games: Price of Anarchy, Universal Worst-Case Examples, and Tightness," *18th Annual European Symposium on Algorithms (ESA)*, pages 17–27, 2010.

63. P. Dhangwatnotai, T. Roughgarden, and Q. Yan, "Revenue Maximization with a Single Sample," *11th Annual ACM Conference on Electronic Commerce (EC)*, pages 129–138, 2010.

64. M. Babaioff and T. Roughgarden, "Equilibrium Efficiency and Price Complexity in Sponsored Search Auctions," Sixth Workshop on Ad Auctions, 2010.

65. A. Roth and T. Roughgarden, "Interactive Privacy via the Median Mechanism," *42nd Annual ACM Symposium on Theory of Computing (STOC)*, pages 765-774, 2010.

66. D. Mosk-Aoyama and T. Roughgarden, "Worst-Case Efficiency Analysis of Queueing Disciplines," *36th International Symposium on Automata, Languages, and Programming (ICALP)*, pages 546–557, 2009.

67. S. Dughmi, T. Roughgarden, and M. Sundararajan, "Revenue Submodularity," *10th Annual ACM Conference on Electronic Commerce (EC)*, 2009, pages 243–252.

68. J. D. Hartline and T. Roughgarden,, "Simple versus Optimal Auctions," *10th Annual ACM Conference on Electronic Commerce (EC)*, pages 225–234, 2009.

69. T. Roughgarden, "Intrinsic Robustness of the Price of Anarchy," *41st Annual ACM Symposium on Theory of Computing (STOC)*, pages 513–522, 2009.

70. A. Ghosh, T. Roughgarden, and M. Sundararajan, "Universally Utility-Maximizing Privacy Mechanisms," *41st Annual ACM Symposium on Theory of Computing (STOC)*, pages 351–359, 2009.

71. A. Motskin, P. Skraba, T. Roughgarden, and L. Guibas, "Lightweight Coloring and Desynchronization for Networks," *28th Annual INFOCOM Conference*, pages 2383–2391, 2009.

72. P. Dhangwatnotai, S. Dobzinski, S. Dughmi, and T. Roughgarden, "Truthful Approximation Schemes for Single-Parameter Agents," *49th Annual Symposium on Foundations of Computer Science (FOCS)*, pages 15–24, 2008.

73. T. Roughgarden, "An Algorithmic Game Theory Primer," *5th IFIP International Conference on Theoretical Computer Science*, pages 21–42, 2008. [Invited survey.]

74. J. D. Hartline and T. Roughgarden, "Money Burning and Optimal Mechanism Design," *40th Annual ACM Symposium on Theory of Computing (STOC)*, pages 75–84, 2008.

75. S. Dobzinski, A. Mehta, T. Roughgarden, and M. Sundararajan, "Is Shapley Cost Sharing Optimal?," *First International Symposium on Algorithmic Game Theory (SAGT)*, pages 327–336, 2008.

76. S. Chawla and T. Roughgarden, "Bertrand Competition in Networks," *First International Symposium on Algorithmic Game Theory (SAGT)*, pages 70–82, 2008.

77. H. Chen, T. Roughgarden, and G. Valiant, "Designing Networks with Good Equilibria," *19th Annual Symposium on Discrete Algorithms (SODA)*, pages 854–863, 2008.

78. R. Krauthgamer and T. Roughgarden, "Metric Clustering via Consistent Labeling," *19th Annual Symposium on Discrete Algorithms (SODA)*, pages 809–818, 2008.

79. D. Mosk-Aoyama, T. Roughgarden, and D. Shah, "Fully Distributed Algorithms for Convex Optimization" *21st International Symposium on Distributed Computing (DISC)*, pages 492–493, 2007.

80. T. Roughgarden and M. Sundararajan, "Optimal Efficiency Guarantees for Network Design Mechanisms," *Twelfth Conference on Integer Programming and Combinatorial Optimization (IPCO)*, pages 469–483, 2007.

81. A. Mehta, T. Roughgarden, and M. Sundararajan, "Beyond Moulin Mechanisms," *8th Annual ACM Conference on Electronic Commerce (EC)*, pages 1–10, 2007.

82. S. Chawla, T. Roughgarden, and M. Sundararajan, "Optimal Cost-Sharing Mechanisms for Network Design," *2nd International Workshop on Internet & Network Economics (WINE)*, pages 112–123, 2006.

83. S. Chawla and T. Roughgarden, "Single-Source Stochastic Routing," *9th International Workshop on Approximation Algorithms for Combinatorial Optimization Problems (APPROX)*, pages 82–94, 2006.

84. T. Roughgarden, "Potential Functions and the Inefficiency of Equilibria," *Proceedings of the International Congress of Mathematicians (ICM)*, Volume III, pages 1071–1094, 2006. [Invited survey.]

85. H. Chen and T. Roughgarden, "Network Design with Weighted Players," *18th ACM Symposium on Parallelism in Algorithms and Architectures (SPAA)*, pages 28–37, 2006.

86. G. Valiant and T. Roughgarden, "Braess's Paradox in Large Random Graphs," *7th Annual ACM Conference on Electronic Commerce (EC)*, pages 296–305, 2006.

87. T. Roughgarden and M. Sundararajan, "New Trade-Offs in Cost-Sharing Mechanisms," *38th Annual ACM Symposium on Theory of Computing (STOC)*, pages 79–88, 2006.

88. M. Enachescu, Y. Ganjali, A. Goel, N. McKeown, and T. Roughgarden, "Routers with Very Small Buffers," *25th Annual INFOCOM Conference*, 2006.

89. R. Cole, Y. Dodis, and T. Roughgarden, "Bottleneck Links, Variable Demand, and the Tragedy of the Commons," *17th Annual Symposium on Discrete Algorithms (SODA)*, pages 668–677, 2006.

90. H. Lin, T. Roughgarden, É. Tardos, and A. Walkover, "Braess's Paradox, Fibonacci Numbers, and Exponential Inapproximability," *32nd International Symposium on Automata, Languages, and Programming (ICALP)*, pages 497–512, 2005.

91. T. Roughgarden, "Selfish Routing with Atomic Players," *16th Annual Symposium on Discrete Algorithms (SODA)*, pages 1184–1185, 2005.

92. C. H. Papadimitriou and T. Roughgarden, "Computing Equilibria in Multi-Player Games," *16th Annual Symposium on Discrete Algorithms (SODA)*, pages 82–91, 2005.

93. E. Anshelevich, A. Dasgupta, J. Kleinberg, É. Tardos, T. Wexler, and T. Roughgarden, "The Price of Stability for Network Design with Fair Cost Allocation," *45th Annual Symposium on Foundations of Computer Science (FOCS)*, pages 295–304, 2004.

94. H. Lin, T. Roughgarden, and É. Tardos, "A Stronger Bound on Braess's Paradox," *15th Annual Symposium on Discrete Algorithms (SODA)*, pages 333–334, 2004.

95. T. Roughgarden, "The Maximum Latency of Selfish Routing," *15th Annual Symposium on Discrete Algorithms (SODA)*, pages 973–974, 2004.

96. A. Gupta, A. Kumar, M. Pál, and T. Roughgarden, "Approximation via Cost-Sharing: A Simple Approximation Algorithm for the Multicommodity Rent-or-Buy Problem," *44th Annual Symposium on Foundations of Computer Science (FOCS)*, pages 606–615, 2003.

97. R. Cole, Y. Dodis, and T. Roughgarden, "Pricing Network Edges for Heterogeneous Selfish Users," *35th Annual ACM Symposium on Theory of Computing (STOC)*, pages 521–530, 2003.

98. A. Gupta, A. Kumar, and T. Roughgarden, "Simpler and Better Approximation Algorithms for Network Design," *35th Annual ACM Symposium on Theory of Computing (STOC)*, pages 365–372, 2003.

99. R. Cole, Y. Dodis, and T. Roughgarden, "How Much Can Taxes Help Selfish Routing?," *4th Annual ACM Conference on Electronic Commerce (EC)*, pages 98–107, 2003.

100. A. Kumar, A. Gupta, and T. Roughgarden, "A Constant-Factor Approximation Algorithm for the Multicommodity Rent-or-Buy Problem," *43rd Annual Symposium on Foundations of Computer Science (FOCS)*, pages 333–342, 2002.

101. T. Roughgarden, "The Price of Anarchy Is Independent of the Network Topology," *34th Annual ACM Symposium on Theory of Computing (STOC)*, pages 428–437, 2002.

102. T. Roughgarden, "How Unfair Is Optimal Routing?," *13th Annual Symposium on Discrete Algorithms (SODA)*, pages 203–204, 2002.

103. T. Roughgarden, "Designing Networks for Selfish Users Is Hard," *42nd Annual Symposium on Foundations of Computer Science (FOCS)*, pages 472–481, 2001.

104. T. Roughgarden, "Stackelberg Scheduling Strategies," *33rd Annual ACM Symposium on Theory of Computing (STOC)*, pages 104–113, 2001.

105. F. A. Chudak, T. Roughgarden, and D. P. Williamson, "Approximate k-MSTs and k-Steiner Trees via the Primal-Dual Method and Lagrangean Relaxation," *Eighth Conference on Integer Programming and Combinatorial Optimization (IPCO)*, pages 60–70, 2001.

106. T. Roughgarden and É. Tardos, "How Bad Is Selfish Routing?," *41st Annual Symposium on Foundations of Computer Science (FOCS)*, pages 93–102, 2000.

Plenary and Keynote Lectures

1. "Beyond Worst-Case Analysis," keynote lecture at the 25th Annual LIDS Student Conference, MIT, Cambridge, MA, January 30, 2020.

2. "How Does Computer Science Inform Modern Auction Design?," keynote lecture at the 39th IARCS Annual Conference on Foundations of Software Technology and Theoretical Computer Science (FSTTCS), Mumbai, India, December 11, 2019.

3. "Data-Driven Optimal Auction Theory," semi-plenary lecture at the 30th International Conference on Game Theory at Stony Brook, Stony Brook, NY, July 15, 2019.

4. "Barriers to Near-Optimal Equilibria," keynote lecture at the Workshop on Twenty Years of the Price of Anarchy,Chania, Greece, July 4, 2019.

5. "Incentives in Proof-of-Work Blockchains," keynote lecture at the Conference on Decentralization, Ann Arbor, MI, April 6, 2019.

6. "How Does Computer Science Inform Modern Auction Design?," keynote lecture at the 26th Annual European Symposium on Algorithms (ESA), Helsinki, Finland, August 21, 2018.

7. "The Surprising Power of Reserve Prices," keynote lecture at the AdKDD & TargetAd Workshop at the 24rd ACM SIGKDD Conference on Knowledge Discovery and Data Mining (KDD), London, England, August 20, 2018.

8. "Learning Near-Optimal Auctions: Statistical, Algorithmic, and Strategic Challenges," keynote lecture at the COST Workshop on Algorithmic Game Theory, Rome, Italy, March 16, 2018.

9. "Learning Near-Optimal Auctions: Statistical, Algorithmic, and Strategic Challenges," keynote lecture at the 1st UK Workshop on Algorithmic Game Theory and Mechanism Design, Oxford, England, March 6, 2018.

10. "Learning Near-Optimal Auctions: Statistical, Algorithmic, and Strategic Challenges," keynote lecture at the 13th International Workshop on Internet & Network Economics (WINE), Bangalore, India, December 19, 2017.

11. "Why Prices Need Algorithms," invited plenary talk, 49th Annual ACM Symposium on Theory of Computing (STOC), Montreal, Canada, June 20, 2017.

12. "Beyond Worst-Case Analysis," keynote lecture at the 2nd Conference on Highlights of Algorithms (HALG), Berlin, Germany, June 11, 2017.

13. "Two Applications of Learning Theory to Algorithmic Game Theory," keynote lecture at the 11th Annual Machine Learning Symposium, New York Academy of Science, New York, NY, March 3, 2017.

14. "Application-Specific Algorithm Selection," Open Lecture, Simons Institute for the Theory of Computing, Berkeley, CA, October 24, 2016.

15. "Intrinsic Robustness of the Price of Anarchy," Kalai Prize Lecture, 5th World Congress of the Game Theory Society, Maastricht, Netherlands, July 27, 2016.

16. "New Connections Between Complexity Theory and Algorithmic Game Theory," keynote lecture at the 8th International Symposium on Algorithmic Game Theory (SAGT), Saarbrücken, Germany, September 30, 2015.

17. "When Do Simple Mechanisms Suffice?," keynote lecture at the 26th International Conference on Game Theory at Stony Brook, Stony Brook, NY, July 22, 2015.

18. "Two Applications of Learning Theory to Algorithmic Game Theory," keynote lecture at the Conference on Learning Theory (COLT), Paris, France, July 5, 2015.

19. "Approximately Optimal Mechanism Design: Motivation, Examples, and Lessons Learned," keynote lecture at the Sixth Annual Southern California Symposium on Network Economics and Game Theory, Caltech, Pasadena, CA, November 21, 2014.

20. "Quantifying Inefficiency in Games and Mechanisms," Social Choice and Welfare Prize Lecture, Boston College, MA, June 21, 2014.

21. "Approximately Optimal Mechanism Design: Motivation, Examples, and Lessons Learned," keynote lecture in the Special Joint EC-NBER-Decentralization Session, Palo Alto, CA, June 9, 2014.

22. "Extension Theorems for the Price of Anarchy," keynote lecture at the Summer Workshop of the Centre for Mathematical Social Sciences, Auckland, New Zealand, December 10, 2013.

23. "Prior-Independent Auctions," keynote lecture at the Workshop on Algorithmic Game Theory, Singapore, January 14, 2013.

24. "Quantifying the Inefficiency of Equilibria," semi-plenary lecture at the Econometric Society Australasian Meeting (ESAM), Melbourne, Victoria, Australia, July 6, 2012.

25. "Simple and Near-Optimal Auctions," semi-plenary lecture at the Society for the Advancement of Economic Theory Conference on Current Trends in Economics (SAET), Brisbane, Queensland, Australia, June 29, 2012.

26. "The Price of Anarchy: Out-of-Equilibrium Guarantees, Intrinsic Robustness, and Beyond," keynote lecture at the Conference on Mathematical Aspects of Game Theory and Applications, Toulouse, France, September 12, 2011.

27. "How To Think About Algorithmic Game Theory," keynote lecture at the CFEM Workshop on New Trends in Mechanism Design, Copenhagen, Denmark, September 7, 2011.

28. "Approximation in Algorithmic Game Theory," keynote lecture at the Workshop on Approximation Algorithms: The Last Decade and the Next, Princeton, NJ, June 17, 2011.

29. "Potential Functions and the Inefficiency of Equilibria," keynote lecture at the Bay Area Discrete Math Day, Berkeley, CA, October 16, 2010.

30. "Robust Price of Anarchy Bounds via Smoothness Arguments," keynote lecture at the Workshop on Advances in Algorithmic Game Theory, CWI Amsterdam, Netherlands, September 2, 2010.

31. "Intrinsic Robustness of the Price of Anarchy," semi-plenary lecture at the 36th International Symposium on Automata, Languages, and Programming (ICALP), special session honoring Christos Papadimitriou, Rhodes, Greece, July 8, 2009.

32. "Scheduling and Algorithmic Game Theory," keynote lecture at the 9th Workshop on Models and Algorithms for Planning and Scheduling Problems (MAPSP), Kerkrade, Netherlands, July 2, 2009.

33. "Intrinsic Robustness of the Price of Anarchy," keynote lecture at the Bellairs Workshop on Algorithmic Game Theory, Bellairs Research Institute, Barbados, March 25, 2009.

34. "Algorithmic Game Theory: A Brief, Biased Introduction," keynote lecture at the 5th IFIP International Conference on Theoretical Computer Science, Milan, Italy, September 9, 2008.

35. "Potentials and Approximation," Shapley Lecture, Third World Congress of the Game Theory Society, Evanston, IL, July 17, 2008.

36. "From Bayesian Auctions to Approximation Guarantees," keynote lecture at the Fourth Workshop on Ad Auctions, Chicago, IL, July 8, 2008.

37. "Designing Network Protocols with Good Equilibria," keynote lecture at the Third Workshop on Future Directions in Distributed Computing, Bertinoro, Italy, June 6, 2007.

38. "Quantifying Inefficiency in Mechanism and Protocol Design," keynote lecture at the DIMAP Workshop on Algorithmic Game Theory, University of Warwick, Conventry, England, March 27, 2007.

39. "Potential Functions and the Inefficiency of Equilibria in Network Games," two keynote lectures at the 32nd Conference on the Mathematics of Operations Research, Lunteren, The Netherlands, January 16 and 17, 2007.

40. "The Price of Anarchy in Network Games," keynote lecture at the DIMACS Workshop on Large-Scale Games, Evanston, IL, April 19, 2005.

41. "Selfish Routing and the Price of Anarchy," keynote lecture at the 14th International Conference on Game Theory at Stony Brook, Stony Brook, NY, July 23, 2003.

42. "Selfish Routing and the Price of Anarchy," keynote lecture at the Workshop on Computer Communication and Networks, Isaac Newton Institute for Mathematical Sciences, Cambridge, England, December 19, 2002.

Public Lectures

1. "How Does Computer Science Inform Modern Auction Design?," Pekeris Lecture, Weizmann Institute, Rehovot, Israel, February 5, 2019.

2. "How Does Computer Science Inform Modern Auction Design?," Public Lecture, Simons Foundation, New York, NY, April 18, 2018.

3. "Game Theory Through the Computational Lens," Lecture Series in Computer Science, Collège de France, Paris, France, January 23, 2018.
4. "Game Theory Through the Computational Lens," Public Lecture, London School of Economics, London, England, November 30, 2017.
5. "Equilibria, Computation, and Compromises," Workshop on Lens of Computation on the Sciences, Institute for Advanced Studies, Princeton, NJ, November 22, 2014.
6. "Quantifying the Inefficiency of Game-Theoretic Equilibria," Lecture Series in Computer Science, Collège de France, Paris, France, November 22, 2012.

Invited Tutorials, Summer Schools, Etc.

1. "Economics and Computer Science: A Conversation," mini-course, Program for Economic Research, Columbia University, New York, NY, March 6–7, 2019.
2. "Data-Driven Optimal Auction Theory," Gaspard Monge Programme for Optimisation and Operations Research lecture series, École Polytechnique, Palaiseau, France, September 14–21, 2017.
3. "When Are Equilibria of Simple Auctions Near-Optimal?," 28th Jerusalem School in Economic Theory, Hebrew University, Jerusalem, July 5–6, 2017.
4. "Complexity Theory in Game Theory and Economics," Barbados Workshop on Computational Complexity (featured speaker), Bellairs Research Institute, Barbados, February 19-24, 2017.
5. "Beyond Worst-Case Analysis," Simons Institute Algorithms and Uncertainty Boot Camp, Berkeley, CA, August 25, 2016.
6. "Near-Optimal Equilibria," Simons Institute Economics and Computation Boot Camp, Berkeley, CA, August 24 and 25, 2015.
7. "Approximation and Algorithmic Game Theory," Simons Symposium on Approximation Algorithms for NP-Hard Problems, Rio Grande, PR, February 23, 2015.
8. "The Price of Anarchy: Intrinsic Robustness and Some Barriers," 6th Annual Winedale Workshop, Winedale, TX, October 17, 2014.
9. "Short Course on Algorithmic Game Theory," Gran Sasso Science Institute, L'Aquila, Italy, March 17–20, 2014.
10. "Algorithmic Game Theory," Lipari School on Computational Complex Systems, Lipari, Italy, July 11–15, 2011.
11. "How To Think About Algorithmic Game Theory," 51st Annual Symposium on Foundations of Computer Science (FOCS), Las Vegas, NV, October 23, 2010.
12. "Bayesian and Worst-Case Revenue-Maximizing Auctions," 5th International Workshop on Internet & Network Economics (WINE), Rome, Italy, December 14, 2009.
13. "Approximation in Algorithmic Game Theory," 10th Max Planck Advanced Course on the Foundations of Computer Science (ADFOCS), Saarbrücken, Germany, September 14, 16, and 18, 2009.
14. "The Inefficiency of Equilibria in Network Games," Summer School on Game Theory in Computer Science, Aarhus, Denmark, June 27 and 28, 2006.
15. "The Price of Anarchy," Tenth Conference on Integer Programming and Combinatorial Optimization (IPCO), New York, NY, June 8, 2004.
16. "The Price of Anarchy," 5th Annual ACM Conference on Electronic Commerce (EC), New York, NY, May 17, 2004.

Invited Colloquia and Seminars

1. "Two Optimal Approximation Algorithms in Submodular Optimization," Computer Science Theory Seminar, Princeton, NJ, November 15, 2019.
2. "Data-Driven Optimal Auction Theory," Economic Theory Seminar, SUNY Albany, NY November 1, 2019.
3. "How Does Computer Science Inform Modern Auction Design?," Computer Science Colloquium, Cornell University, Ithaca, NY, October 31, 2019.
4. "How Does Computer Science Inform Modern Auction Design?," Computer Science Colloquium, Yale University, New Haven, CT, October 9, 2019.
5. "Data-Driven Optimal Auction Theory," Economic Theory Seminar, Yale University, New Haven, CT, October 9, 2019.
6. "How Does Computer Science Inform Modern Auction Design?," Academic Seminar Series, Two Sigma, New York, NY, August 19, 2019.
7. "Distribution-Free Models of Social and Information Networks," Lab Colloquium, Microsoft Research, New York, NY May 28, 2019.
8. "Distribution-Free Models of Social and Information Networks," Theory Seminar, University of Pennsylvania, PA, April 19, 2019.
9. "Distribution-Free Models of Social and Information Networks," Computer Science Colloquium, Technion, Haifa, Israel, February 7, 2019.
10. "How Does Computer Science Inform Modern Auction Design?," Distinguished Lecture, SUNY Stony Brook, NY, October 26, 2018.
11. "How Does Computer Science Inform Modern Auction Design?," SCS Distinguished Lecture, Georgia Tech, Atlanta, GA, October 5, 2018.
12. "How Does Computer Science Inform Modern Auction Design?," Beer & Tech Seminar, Criteo, Paris, France, June 6, 2018.
13. "Data-Driven Optimal Auction Theory," Micro Workshop, Adam Smith Business School, Universität Bonn, Germany, May 30, 2018.
14. "How Does Computer Science Inform Modern Auction Design?," Game Theory Seminar, Corvinus University of Budapest, Hungary, May 29, 2018.
15. "How Does Computer Science Inform Modern Auction Design?," Computer Science Department Colloquium, University of Liverpool, England, May 24, 2018.
16. "Data-Driven Optimal Auction Theory," Microtheory Research Seminar, Adam Smith Business School, University of Glasgow, Scotland, May 22, 2018.
17. "Distribution-Free Models of Social and Information Networks," Theory Seminar, University of Oxford, England, April 26, 2018.
18. "How Does Computer Science Inform Modern Auction Design?," Operations Research & Financial Engineering Department Colloquium, Princeton University, Princeton, NJ, April 17, 2018.
19. "How Does Computer Science Inform Modern Auction Design?," Computer Science Department Colloquium, New York University, New York, NY, April 2, 2018.
20. "Distribution-Free Models of Social and Information Networks," Math Colloquium, Queen Mary University of London, England, March 12, 2018.

21. "How Does Computer Science Inform Modern Auction Design?," Computer Science Department Colloquium, University of Warwick, Coventry, England, February 14, 2018.
22. "Game Theory Through the Computational Lens," Colloquium, Sapienza School for Advanced Studies, Rome, Italy December 14, 2017.
23. "Data-Driven Optimal Auction Theory," Economics Seminar, LUISS Guido Carli, Rome, Italy, December 5, 2017.
24. "Distribution-Free Models of Social and Information Networks," Seminar on Combinatorics, Games, and Optimisation, London School of Economics, London, England, November 16, 2017.
25. "Distribution-Free Models of Social and Information Networks," IC Colloquium, EPFL, Lausanne, Switzerland, November 9, 2017.
26. "How Does Computer Science Inform Modern Auction Design?," Distinguished Lecture Series, Columbia University, New York, NY, November 1, 2017.
27. "How Does Computer Science Inform Modern Auction Design?," Colloquium, Technische Universität Berlin, Berlin, Germany, October 23, 2017.
28. "How Does Computer Science Inform Modern Auction Design?," Distinguished Lecture in Computer Science, University of Illinois, Urbana-Champaign, IL, September 11, 2017.
29. "Data-Driven Optimal Auction Theory," Game Theory Seminar, Technion, Haifa, Israel, July 9, 2017.
30. "How Hard Is Inference for Structured Prediction?," Northwestern University Quarterly Theory Workshop, Evanston, IL, May 24, 2017.
31. "How Does Computer Science Inform Modern Auction Design?," Computer Science Theory Seminar, University of Washington, Seattle, WA, May 16, 2017.
32. "How Hard Is Inference for Structured Prediction?," Theory Seminar, Microsoft Research, Redmond, WA, May 15, 2017.
33. "Data-Driven Optimal Auction Theory," Economics Department Seminar, Pennsylvania State University, State College, PA, April 7, 2017.
34. "How Does Computer Science Inform Modern Auction Design?," Computer Science Theory Seminar, Pennsylvania State University, State College, PA, April 6, 2017.
35. "How Does Computer Science Inform Modern Auction Design?," Theory of Computation Colloquium, MIT, Cambridge, MA, November 29, 2016.
36. "Data-Driven Optimal Auction Theory," Economic Theory Seminar, Department of Economics, Stanford University, CA, October 19, 2016.
37. "Data-Driven Optimal Auction Theory," Market Design Seminar, Columbia Business School, New York, NY, September 30, 2016.
38. "How Does Computer Science Inform Modern Auction Design?," IBM Accelerated Discovery Lab Distinguished Speaker Forum, IBM Almaden, San Jose, CA, August 9, 2016.
39. "Learning Near-Optimal Auctions and Heuristics," Joint Algorithms-Machine Learning Seminar, Google, Inc., Mountain View, CA, May 24, 2016.
40. "How Does Computer Science Inform Modern Auction Design?," CCDC Seminar, University of California at Santa Barbara, Santa Barbara, CA, May 13, 2016.
41. "Learning Near-Optimal Auctions and Heuristics," Machine Learning Colloquium, Carnegie Mellon University, Pittsburgh, PA, April 28, 2016.

42. "Learning Near-Optimal Auctions and Heuristics," Northwestern University Quarterly Theory Workshop, Evanston, IL, March 7, 2016.

43. "The Sample Complexity of Near-Optimal Auctions and Heuristics," Joint Algorithms-Machine Learning Seminar, Google, Inc., New York, NY, January 15, 2016.

44. "How Does Computer Science Inform Modern Auction Design?," Seminar on Algorithms, Data Structures, and Applications, ETH Zurich, Zurich, Switzerland, November 24, 2015.

45. "How Does Computer Science Inform Modern Auction Design?," IC Colloquium, EPFL, Lausanne, Switzerland, November 23, 2015.

46. "New Connections Between Complexity Theory and Algorithmic Game Theory," TCS+ Seminar (online), November 11, 2015.

47. "New Connections Between Complexity Theory and Algorithmic Game Theory," Theory Seminar, Columbia University, New York, NY, September 25, 2015.

48. "Barriers to Near-Optimal Equilibria," Theory Lunch Seminar, UC Berkeley, Berkeley, CA, March 4, 2015.

49. "Barriers to Near-Optimal Equilibria," Theory Seminar, IBM Almaden, San Jose, CA, October 14, 2014.

50. "Barriers to Near-Optimal Equilibria," Theory Seminar, Microsoft Research, Mountain View, CA, September 17, 2014.

51. "Approximately Optimal Mechanism Design: Motivation, Examples, and Lessons Learned," International Seminar Series on Economics with Policy, Hungarian Academy of Sciences, Budapest, Hungary, September 11, 2014.

52. "Beyond Worst-Case Analysis in Auctions, Classification, and Network Analysis," Theory Seminar, Brown University, Providence, RI, May 9, 2014.

53. "Approximation in Algorithmic Game Theory," EconCS Seminar, UC Berkeley, Berkeley, CA, April 8, 2014.

54. "Approximation in Algorithmic Game Theory," Algorithmic Economics Seminar, Carnegie Mellon University, Pittsburgh, PA, March 11, 2014.

55. "Extension Theorems for the Price of Anarchy," Mathematics Department Colloquium, Stanford University, Stanford, CA, February 27, 2014.

56. "Beyond Worst-Case Analysis in Auctions, Classification, and Network Analysis," Computer Science Department Colloquium, University of Auckland, New Zealand, December 12, 2013.

57. "Beyond Worst-Case Analysis in Auctions, Classification, and Network Analysis," Computer Science Department Colloquium, Harvard University, Cambridge, MA, November 21, 2013.

58. "Extension Theorems for the Price of Anarchy," Distinguished Capitol Area Theory Seminar, University of Maryland, College Park, MD, May 3, 2013.

59. "Quantifying the Inefficiency of Game-Theoretic Equilibria," Geometry Seminar, Courant Institute of Mathematics, New York University, New York, NY, April 30, 2013.

60. "Extension Theorems for the Price of Anarchy," Computer Engineering and Systems Group Fish Bowl Seminar Series, Texas A & M, College Station, TX, April 11, 2013.

61. "Extension Theorems for the Price of Anarchy," Lab Colloquium, Microsoft Research, New York, NY, April 9, 2013.

62. "Intractability in Algorithmic Game Theory," Computer Science Seminar, Institute for Advanced Studies, Princeton, NJ, March 11, 2013.

63. "Simple and Prior-Independent Auctions," Theory Seminar, Princeton University, Princeton, NJ, February 22, 2013.

64. "Porting the Computer Science Toolbox to Game Theory and Economics," Computational Mathematics Colloquium, University of Waterloo, Waterloo, Canada, October 29, 2012.

65. "Porting the Computer Science Toolbox to Game Theory and Economics," Computer Science Department Colloquium, McGill University, Montreal, Canada, October 26, 2012.

66. "Porting the Computer Science Toolbox to Game Theory and Economics," Computer Science Department Colloquium, New York University, New York, NY, October 5, 2012.

67. "The Price of Anarchy: Out-of-Equilibrium Guarantees, Intrinsic Robustness, and Beyond," Computer Science Theory Seminar, Rutgers University, New Brunswick, NJ, September 26, 2012.

68. "The Price of Anarchy: Out-of-Equilibrium Guarantees, Intrinsic Robustness, and Beyond," Economic Theory Seminar, University of Pennsylvania, Philadelphia, PA, September 18, 2012.

69. "Porting the Computer Science Toolbox to Game Theory and Economics," Triangle Computer Science Distinguished Lecturer Series, Duke University, Durham, NC, September 10, 2012.

70. "Simple and Near-Optimal Auctions," Microeconomic Theory Seminar, Australian National University, Canberra, Australia, July 9, 2012.

71. "The Price of Anarchy in Games of Incomplete Information," Theory of Computation Colloquium, MIT, Cambridge, MA, April 24, 2012.

72. "The Price of Anarchy: Out-of-Equilibrium Guarantees, Intrinsic Robustness, and Beyond," Seminar on Applied Theory, University of Chicago Booth School of Business, Chicago, IL, March 26, 2012.

73. "Proof Techniques for Bounding the Price of Anarchy," Computer Science Theory Seminar, University of California at Santa Barbara, Santa Barbara, CA, March 6, 2012.

74. "Porting the Computer Science Toolbox to Game Theory and Economics," Computer Science Department Colloquium, University of California at Santa Barbara, Santa Barbara, CA, March 5, 2012.

75. "The Price of Anarchy: Out-of-Equilibrium Guarantees, Intrinsic Robustness, and Beyond," Barcelona Jocs Seminar, Barcelona, Spain, February 27, 2012.

76. "The Price of Anarchy: Out-of-Equilibrium Guarantees, Intrinsic Robustness, and Beyond," Microeconomic Theory Seminar, Cowles Foundation, New Haven, NJ, February 22, 2012.

77. "The Price of Anarchy: Out-of-Equilibrium Guarantees, Intrinsic Robustness, and Beyond," Computer Science Theory Seminar, New York University, New York, NY, February 9, 2012.

78. "Porting the Computer Science Toolbox to Game Theory and Economics," Computer Science Department Colloquium, Princeton University, Princeton, NJ, February 8, 2012.

79. "Selfish Routing and the Price of Anarchy," Mathematics Department Colloquium, San Jose State, San Jose, CA, November 2, 2011.

80. "Robust Guarantees on Algorithmic Game Theory," EECS Department Colloquium, UC Berkeley, Berkeley, CA, October 5, 2011.

81. "Algorithmic Game Theory: Toward Robust Guarantees," Computer Science Department Colloquium, Washington University, St. Louis, MO, September 23, 2011.

82. "Simple Auctions with Near-Optimal Equilibria," Research on Algorithms and Incentives in Networks (RAIN) Seminar, Stanford, CA, April 27, 2011.

83. “The Price of Anarchy: Out-of-Equilibrium Guarantees, Intrinsic Robustness, and Beyond,” Theory Seminar, Weizmann Institute, Rehovot, Israel, April 11, 2011.
84. “The Price of Anarchy: Out-of-Equilibrium Guarantees, Intrinsic Robustness, and Beyond,” Computer Science Department Colloquium, Hebrew University, Jerusalem, Israel, April 4, 2011.
85. “From Bayesian to Worst-Case Optimal Auction Design,” Economics and Computation Seminar, Hebrew University, Jerusalem, Israel, March 27, 2011.
86. “Intrinsic Robustness of the Price of Anarchy,” Game Theory and Human Behavior Seminar, USC, Los Angeles, CA November 16, 2010.
87. “From Bayesian to Worst-Case Optimal Auction Design,” Colloquium, Department of Computer Science, USC, Los Angeles, CA November 15, 2010.
88. “Intrinsic Robustness of the Price of Anarchy,” Departmental Seminar, Economics Department, University of Hawaii, Honolulu, HI, November 5, 2011.
89. “Algorithmic Game Theory: Two Vignettes,” Symbolic Systems Forum, Stanford, CA, May 27, 2010.
90. “Revenue Maximization with a Single Sample,” Theory Seminar, Microsoft Research, Redmond, WA, May 5, 2010.
91. “Intrinsic Robustness of the Price of Anarchy,” STIET Seminar, University of Michigan, Ann Arbor, MI, April 15, 2010.
92. “Intrinsic Robustness of the Price of Anarchy,” Economic Theory Seminar, Northwestern University, Evanston, IL, April 14, 2010.
93. “Revenue Maximization with a Single Sample,” Computer Science Theory Seminar, Northwestern University, Evanston, IL, April 12, 2010.
94. “Intrinsic Robustness of the Price of Anarchy,” ARC Colloquium, Georgia Tech, Atlanta, GA, April 5, 2010.
95. “Intrinsic Robustness of the Price of Anarchy,” Optimization Seminar, UC Davis, Davis, CA, March 1, 2010.
96. “Intrinsic Robustness of the Price of Anarchy,” Pauli Colloquium, Wolfgang Pauli Institute, Vienna, Austria, December 18, 2009.
97. “Intrinsic Robustness of the Price of Anarchy,” Operations Research Seminar, Stanford University, Stanford, CA, October 28, 2009.
98. “Intrinsic Robustness of the Price of Anarchy,” Theory Seminar, University of Washington, Seattle, WA, October 6, 2009.
99. “Intrinsic Robustness of the Price of Anarchy,” Lab Colloquium, Microsoft Research, Mountain View, CA, September 3, 2009.
100. “Intrinsic Robustness of the Price of Anarchy,” Theory Seminar, Cornell University Ithaca, NY, June 18, 2009.
101. “Intrinsic Robustness of the Price of Anarchy,” Mathematics Department Seminar, London School of Economics, London, England, June 11, 2009.
102. “Intrinsic Robustness of the Price of Anarchy,” Lab Colloquium, Microsoft Research, Cambridge, MA, May 20, 2009.
103. “Algorithmic Game Theory: Two Vignettes,” Distinguished Lecture Series, Department of Computer Science and Engineering, Arizona State University, Tempe, AZ, April 8, 2009.

104. "Intrinsic Robustness of the Price of Anarchy," Departmental Seminar, Economics Department, Vanderbilt University, Nashville, TN, April 6, 2009.

105. "Algorithmic Game Theory: Two Vignettes," Computer Systems Colloquium, Stanford University, Stanford, CA, March 11, 2009.

106. "From Bayesian to Worst-Case Optimal Auctions," Theory of Computation Colloquium, MIT, Cambridge, MA, October 14, 2008.

107. "Probability in Algorithmic Game Theory: Two Surprising Appearances," Interdisciplinary Stochastic Processes Colloquium, UC Berkeley, Berkeley, CA, September 16, 2008.

108. "From Bayesian to Worst-Case Optimal Auction Design," Theory Seminar, Google, Inc., New York, NY, June 6, 2008.

109. "Optimal Protocol Design in Networks with Selfish Users," Joint Economics-Theory Seminar, Cornell University, Ithaca, NY, August 28, 2007.

110. "Optimal Protocol Design in Networks with Selfish Users," Colloquium, Technische Universität Berlin, Berlin, Germany, June 29, 2007.

111. "Quantifying Trade-Offs in Networks and Auctions," Colloquium, Technische Universität München, Munich, Germany, June 26, 2007.

112. "Quantifying Trade-Offs in Networks and Auctions," Colloquium, Department of Computer Science, Wayne State University, Detroit, MI, April 16, 2007.

113. "Optimal Cost-Sharing Mechanisms," Theory Seminar, University of California at Berkeley, Berkeley, CA, September 11, 2006.

114. "Selfish Routing and the Price of Anarchy," Economic Theory Seminar, University of Wisconsin-Madison, Madison, WI, September 8, 2006.

115. "Optimal Cost-Sharing Mechanisms," Theory Seminar, University of Wisconsin-Madison, Madison, WI, September 7, 2006.

116. "Optimal Cost-Sharing Mechanisms," Theory Seminar, IBM Almaden, San Jose, CA, September 5, 2006.

117. "Optimal Cost-Sharing Mechanisms," Theory Seminar, Microsoft Research, Mountain View, CA, August 11, 2006.

118. "Approximately Efficient Cost-Sharing Mechanisms," Operations Research Seminar, Stanford University, Stanford, CA, May 3, 2006.

119. "Bounding Braess's Paradox," Theory Seminar, Universitá di Roma, Rome, Italy, June 17, 2005.

120. "Networks, Game Theory, and the Price of Anarchy," Symbolic Systems Forum, Stanford, CA, May 5, 2005.

121. "Selfish Routing and the Price of Anarchy," Annual Meeting of the National Academy of Sciences, Washington D.C., May 1, 2005.

122. "Selfish Routing and the Price of Anarchy," Advanced Network Colloquium Series, University of Maryland, College Park, MD, April 22, 2005.

123. "Computing (Correlated) Equilibria in Multi-Player Games," HP Labs Algorithms Seminar, Palo Alto, CA, February 18, 2005.

124. "Selfish Routing and the Price of Anarchy," HP Labs Algorithms Seminar, Palo Alto, CA, February 11, 2005.

125. “Computing (Correlated) Equilibria in Multi-Player Games,” Bay Area Theory Symposium (BATS), Berkeley, CA, December 10, 2004.

126. “Selfish Routing and the Price of Anarchy,” Economic Theory Seminar, Northwestern University, Evanston, IL, September 22, 2004.

127. “Computing (Correlated) Equilibria in Multi-Player Games,” Theory Seminar, University of Pennsylvania, Philadelphia, PA, August 25, 2004.

128. “Selfish Routing and the Price of Anarchy,” Interdisciplinary Seminar in Game Theory, London School of Economics, London, England, July 2, 2004.

129. “Designing Networks by Flipping Coins,” Theory Seminar, IBM Watson, Yorktown Heights, NY, May 26, 2004.

130. “Designing Networks by Flipping Coins,” Theory Seminar, Princeton University, Princeton, NJ, May 13, 2004.

131. “Designing Networks by Flipping Coins,” Theory Seminar, Columbia University, New York, NY, May 10, 2004.

132. “Designing Networks by Flipping Coins,” Theory Seminar, University of California at Berkeley, Berkeley, CA, May 7, 2004.

133. “Selfish Routing and the Price of Anarchy,” Theory Seminar, Department of Economics, University of California at San Diego, San Diego, CA, April 14, 2004.

134. “Selfish Routing and the Price of Anarchy,” Operations, Information, and Technology Seminar, Graduate School of Business, Stanford University, Stanford, CA, April 7, 2004.

135. “Selfish Routing and the Price of Anarchy,” Operations and Logistics Seminar, Sauder School of Business, University of British Columbia, Vancouver, Canada, March 22, 2004.

136. “Selfish Routing and the Price of Anarchy,” Colloquium, Department of Computer Science, Brown University, Providence, RI, March 18, 2004.

137. “Bounding Braess’s Paradox,” Algorithmic Game Theory Seminar, MIT, Cambridge, MA, March 17, 2004.

138. “Designing Networks by Flipping Coins,” Theory Seminar, Harvard University, Cambridge, MA, March 17, 2004.

139. “Designing Networks by Flipping Coins,” Theory Seminar, MIT, Cambridge, MA, March 16, 2004.

140. “Selfish Routing and the Price of Anarchy,” Applied Mathematics Colloquium, MIT, Cambridge, MA, March 15, 2004.

141. “Selfish Routing and the Price of Anarchy,” Networking Seminar, Stanford University, Stanford, CA, January 15, 2004.

142. “Pricing Networks with Selfish Routing,” Theory Seminar, IBM Almaden, San Jose, CA, December 12, 2003.

143. “Selfish Routing and the Price of Anarchy,” Frontiers of Management Science Colloquium, Department of Management Science & Engineering, Stanford University, Stanford, CA, November 21, 2003.

144. “Selfish Routing and the Price of Anarchy,” Colloquium, Department of Electrical Engineering and Computer Science, California Institute of Technology, Pasadena, CA, November 5, 2003.

145. “Pricing Networks with Selfish Routing,” Multi-Agent Systems Seminar, Stanford University, Stanford, CA, October 16, 2003.

146. "Selfish Routing and the Price of Anarchy," Colloquium, Department of Industrial Engineering and Operations Research, UC Berkeley, Berkeley, CA, September 22, 2003.
147. "Selfish Routing and the Price of Anarchy," Networking, Communications, and DSP Seminar, UC Berkeley, Berkeley, CA, September 16, 2003.
148. "Selfish Routing and the Price of Anarchy," Theory Seminar, IBM Watson, Yorktown Heights, NY, July 25, 2003.
149. "Selfish Routing and the Price of Anarchy," Engineering Systems Division Seminar, MIT, Cambridge, MA, May 21, 2003.
150. "Selfish Routing and the Price of Anarchy," Colloquium, Division of Decisions, Risk, and Operations, Columbia University Business School, New York, NY, May 1, 2003.
151. "Selfish Routing and the Price of Anarchy," Colloquium, Department of Computer Science, UC San Diego, San Diego, CA, April 28, 2003.
152. "Selfish Routing and the Price of Anarchy," Colloquium, Department of Computer Science, Stanford University, Stanford, CA, April 19, 2003.
153. "Selfish Routing and the Price of Anarchy," Colloquium, Department of Computer Science, University of Toronto, Toronto, Ontario, Canada, April 8, 2003.
154. "Selfish Routing and the Price of Anarchy," Theory Seminar, Microsoft Research, Redmond, WA, April 3, 2003.
155. "Selfish Routing and the Price of Anarchy," Colloquium, Department of Computer Science, University of Washington, Seattle, WA, April 1, 2003.
156. "Selfish Routing and the Price of Anarchy," Theory Seminar, IBM Almaden, San Jose, CA, March 27, 2003.
157. "Selfish Routing and the Price of Anarchy," Theory Seminar, Microsoft Research, Mountain View, CA, March 24, 2003.
158. "Selfish Routing and the Price of Anarchy," Colloquium, Department of Industrial Engineering and Operations Research, Columbia University, New York, NY, March 12, 2003.
159. "Selfish Routing and the Price of Anarchy," Colloquium, Department of Electrical Engineering and Computer Science, MIT, Cambridge, MA, March 10, 2003.
160. "Selfish Routing and the Price of Anarchy," Colloquium, Department of Computer Science, University of Wisconsin-Madison, Madison, WI, March 6, 2003.
161. "Selfish Routing and the Price of Anarchy," Colloquium, Department of Computer Science, UCLA, Los Angeles, CA, February 27, 2003.
162. "Selfish Routing and the Price of Anarchy," Colloquium, Department of Computer Science, University of Chicago, Chicago, IL, February 24, 2003.
163. "Selfish Routing and the Price of Anarchy," Aladdin Theory Lunch, Carnegie Mellon University, Pittsburgh, PA, February 19, 2003.
164. "Selfish Routing and the Price of Anarchy," Algorithms and Complexity Seminar, University of Pennsylvania, Philadelphia, PA, November 8, 2002.
165. "The Elusiveness of Braess's Paradox: Designing Networks for Selfish Users Is Hard," Institute for Advanced Studies Seminar in Theoretical Computer Science, Princeton, NJ, October 7, 2002.
166. "Selfish Routing and the Price of Anarchy," Princeton Seminar in Theoretical Computer Science, Princeton, NJ, October 4, 2002.

167. "Selfish Routing and the Price of Anarchy," Operations Research Seminar Series, MIT, Cambridge, MA, September 24, 2002.
168. "Selfish Routing and the Price of Anarchy," Mathematics Research Colloquium, Lucent Bell Labs, Murray Hill, NJ, August 1, 2002.
169. "Selfish Routing," Colloquium, European Graduate Program in Combinatorics, Geometry, and Computation, Technische Universität Berlin, Berlin, Germany, June 25, 2002.
170. "The Price of Anarchy Is Independent of the Network Topology," Theory Seminar, Cornell University, Ithaca, NY, May 6, 2002.
171. "Designing Networks for Selfish Users Is Hard," Theory Seminar, Cornell University, Ithaca, NY, September 24, 2001.
172. "Selfish Routing," Theory Seminar, IBM Almaden, San Jose, CA, August 9, 2001.
173. "Approximate k-MSTs and k-Steiner Trees via the Primal-Dual Method and Lagrangean Relaxation," Theory Seminar, IBM Almaden, San Jose, CA, June 8, 2001.
174. "Stackelberg Scheduling Strategies," Theory Seminar, Cornell University, Ithaca, NY, April 23, 2001.
175. "How Bad Is Selfish Routing?," Operations Research Seminar, GSIA, Carnegie Mellon University, Pittsburgh, PA, December 4, 2000.
176. "How Bad Is Selfish Routing?," Theory Seminar, Cornell University, Ithaca, NY, October 23, 2000.

Invited Conference and Workshop Presentations

1. "An Axiomatic Approach to Block Rewards," Stanford Blockchain Conference, Stanford, CA, February 21, 2020.
2. "Complexity-Theoretic Barriers for Prices and Mechanisms," Workshop on Complexity in Algorithmic Game Theory, Mumbai, India, December 10, 2019.
3. "Data-Driven Algorithm Design," New York Area Theory Day, New York University, New York, NY, December 6, 2019.
4. "Distribution-Free Models of Social Networks," Workshop on Beyond Worst-Case Analysis, 60th Annual Symposium on Foundations of Computer Science (FOCS), Baltimore, MD, November 9, 2019.
5. "Incentive-Compatibility in Blockchains and Mining Pools," Simons Workshop on Large-Scale Consensus and Blockchains, Berkeley, CA, October 25, 2019.
6. "An Axiomatic Approach to Block Rewards," First ACM Conference on Advances in Financial Technology (AFT), Zurich, Switzerland, October 22, 2019.
7. "Data-Driven Algorithm Design," Workshop on Learning-Augmented Algorithms, Toyota Technology Institute, Chicago, IL, August 12, 2019.
8. "Data-Driven Optimal Auction Theory," Workshop on Automated Algorithm Design, Toyota Technology Institute, Chicago, IL, August 8, 2019.
9. "Simple Versus Optimal Contracts," Stony Brook Workshop on Simplicity and Robustness in Complex Markets, Stony Brook, NY, July 12, 2019.
10. "Application-Specific Algorithm Selection," STOC Workshop on New Frontiers of Automated Mechanism Design for Pricing and Auctions, Phoenix, AZ, June 23, 2019.
11. "Complexity-Theoretic Barriers for Prices and Mechanisms," Workshop on Network Games, Tropical Geometry, and Quantum Communication, Berlin, Germany, June 4, 2019.

12. "The Surprising Power of Reserve Prices," WebConference Workshop on the Intersection of Machine Learning and Mechanism Design, San Francisco, CA, May 13, 2019.
13. "A Data-Driven Approach to Auction Reserve Prices," Data Science Day, Columbia University, New York, NY, April 3, 2019.
14. "Learning Near-Optimal Auctions," 5th Google Market Algorithms Workshop, Mountain View, CA, February 22, 2019.
15. "Characterizing Incentive-Compatible Blockchains," DARPA Workshop on Applications and Barriers to Consensus Protocols (ABC), Arlington, VA, February 14, 2019.
16. "Fair Division with Combinatorial Valuations," Israel Algorithmic Game Theory Day, Weizmann Institute, Rehovot, Israel, February 3, 2019.
17. "Toward Incentive-Compatible Blockchains," Dagstuhl Workshop on Blockchain Security at Scale, Wadern, Germany, November 15, 2018.
18. "When Are Equilibria of Simple Auctions Near-Optimal?," Symposium on Auctions and Computational Game Theory in Honour of Robert Wilson, London School of Economics, London, England, July 11, 2018.
19. "Distribution-Free Models of Social and Information Networks," Workshop on Data Science Theory and Practice, London School of Economics, London, England, March 27, 2018.
20. "Data-Driven Optimal Auction Theory," Cemmap Conference on Optimisation and Machine Learning in Economics, University College London, England, March 8, 2018.
21. "Don, Matroids, and Stable Matchings," Knuth80 Workshop on Algorithms, Combinatorics, and Information, Piteå, Sweden, January 8, 2018.
22. "Learning Near-Optimal Auctions, Submodular Maximization, and Offline-to-Online Reductions," Workshop on Data-driven Algorithmics, Bertinoro, Italy, Noember 7, 2017.
23. "When Are Welfare Guarantees Robust?," 20th International Workshop on Approximation Algorithms for Combinatorial Optimization Problems (APPROX), Berkeley, CA, August 16, 2017.
24. "On a Theorem of Kalai and Samet: When Do Pure Equilibria Imply a Potential Function?," Games and Economic Behavior Workshop (in honor of Ehud Kalai), Tel Aviv, Israel, July 11, 2017.
25. "Learning Simple Auctions," Workshop on Connections between Theory of Computing and Mechanism Design, (STOC workshop), Montreal, Canada, June 23, 2017.
26. "New Connections Between Complexity Theory and Algorithmic Game Theory," Young Researcher Workshop on Economics and Computation, Tel Aviv University, Israel, January 5, 2017.
27. "How Does Computer Science Inform Modern Auction Design?," Ninth Israel CS Theory Day, Open University, Ra'anana, Israel, January 3, 2017.
28. "How Hard Is Inference for Structured Prediction?," Workshop on Learning, Algorithm Design and Beyond Worst-Case Analysis, Simons Institute for the Theory of Computing, November 18, 2016.
29. "Outposts Between Average- and Worst-Case Analysis: A Case Study in Auction Design," Workshop on Uncertainty in Computation, Simons Institute for the Theory of Computing, October 7, 2016.
30. "Distribution-Free Models of Social and Information Networks," Workshop on Optimization and Decision-Making Under Uncertainty, Simons Institute for the Theory of Computing, September 21, 2016.
31. "A Learning Approach to Application-Specific Algorithm Selection," Workshop on Information Theory and Applications, La Jolla, CA, February 5, 2016.

32. “Quantifying Inefficiency in Games and Auctions,” Conference Honoring Hugo Sonnenschein, Becker Friedman Institute, University of Chicago, Chicago, IL, October 24, 2015.

33. “The Pseudo-Dimension of Near-Optimal Auctions,” Workshop on Complexity and Simplicity in Economics, Simons Institute for the Theory of Computing, October 16, 2015.

34. “The Sample Complexity of Learning Near-Optimal Auctions and Heuristics,” Workshop on Data-driven Algorithmics, Harvard University, Cambridge, MA, September 10, 2015.

35. “Barriers to Near-Optimal Equilibria,” 22nd International Symposium on Mathematical Programming (ISMP), Pittsburgh, PA, July 16, 2015.

36. “Barriers to Near-Optimal Equilibria,” Workshop on Strategic Behavior and Phase Transitions in Random and Complex Combinatorial Structures, Barcelona, Spain, June 8, 2015.

37. “Making the Most of Your Samples,” Workshop on Information Theory and Applications, La Jolla, CA, February 1, 2015.

38. “Barriers to Near-Optimal Equilibria,” 55th Annual Symposium on Foundations of Computer Science (FOCS), Philadelphia, PA, October 19, 2014.

39. “Decompositions of Triangle-Dense Graphs,” Dagstuhl Workshop on Beyond Worst-Case Analysis, Wadern, Germany, September 8, 2014.

40. “Decompositions of Triangle-Dense Graphs,” 7th Workshop on Flexible Network Design, Lugano, Switzerland, July 31, 2014.

41. “The Sample Complexity of Revenue-Maximization,” 46th Annual ACM Symposium on Theory of Computing (STOC), New York, NY, June 1, 2014.

42. “Approximate Recovery of Binary Classifications,” Workshop on Information Theory and Applications, La Jolla, CA, February 14, 2014.

43. “The Price of Anarchy in Games of Incomplete Information,” Workshop on Computational Game Theory, Stony Brook, NY, July 17, 2013.

44. “The Price of Anarchy in Games of Incomplete Information,” Workshop on Trends in Mechanism Design II, Aarhus, Denmark, June 25, 2013.

45. “Extension Theorems for the Price of Anarchy,” New York Area Theory Day, New York University, New York, NY, May 10, 2013.

46. “Optimal and Near-Optimal Auction Design with Interdependent Values,” Dagstuhl Workshop on the Interface of Computation, Game Theory, and Economics, Wadern, Germany, April 18, 2013.

47. “Intractability in Algorithmic Game Theory,” Workshop on Modeling Intractability, Mitzpe Ramon, Israel, February 12, 2013.

48. “Prior-Independent Auctions,” 5th New York Computer Science & Economics (NYCE) Day, New York, NY, December 3, 2012.

49. “Simple and Prior-Independent Auctions,” FOCS Workshop on Bayesian Mechanism Design, New Brunswick, NJ, October 20, 2012.

50. “Prior-Independent Auctions,” Fourth World Congress of the Game Theory Society, Istanbul, Turkey, July 26, 2012.

51. “The Price of Anarchy in Games of Incomplete Information,” 13th Annual ACM Conference on Electronic Commerce (EC), Valencia, Spain, June 5, 2012.

52. “Simple and Near-Optimal Auctions,” Google Research Workshop, New York, NY, May 23, 2012.

53. "The Price of Anarchy: Out-of-Equilibrium Guarantees, Intrinsic Robustness, and Beyond," NSF/CEME Conference on Decentralization, Pasadena, CA, March 31, 2012.
54. "Restoring Pure Equilibria to Weighted Congestion Games," 38th International Symposium on Automata, Languages, and Programming (ICALP), Zurich, Switzerland, July 6, 2011.
55. "Simple and Near-Optimal Auctions," Workshop on Innovations in Algorithmic Game Theory, Jerusalem, Israel, May 26, 2011.
56. "Intrinsic Robustness of the Price of Anarchy," IPAM Workshop on Algorithmic Game Theory, Los Angeles, CA, January 10, 2011.
57. "Intrinsic Robustness of the Price of Anarchy," Forty-Eighth Annual Allerton Conference on Communication, Control, and Computing, Monticello, IL, September 30, 2010.
58. "Intrinsic Robustness of the Price of Anarchy," SIAM Conference on Discrete Mathematics, Austin, TX, June 14, 2010.
59. "Equilibrium Efficiency and Price Complexity in Sponsored Search Auctions," Sixth Workshop on Ad Auctions, Cambridge, MA, June 8, 2010.
60. "Revenue Maximization with a Single Sample," Workshop on Prior-Free Mechanism Design, Guanajuato, Mexico, May 20, 2010.
61. "Revenue Maximization with a Single Sample," Workshop on Frontiers in Mechanism Design, Bertinoro, Italy, March 15, 2010.
62. "Intrinsic Robustness of the Price of Anarchy," Workshop on Distributed Decisions via Games and Price Mechanisms, Lund University, Lund, Sweden, March 10, 2010.
63. "Intrinsic Robustness of the Price of Anarchy," 20th International Symposium on Mathematical Programming (ISMP), Chicago, IL, August 24, 2009.
64. "Worst-Case Efficiency Analyses of Queueing Disciplines," 36th International Symposium on Automata, Languages, and Programming (ICALP), Rhodes, Greece, July 10, 2009.
65. "Universally Utility-Maximizing Privacy Mechanisms," ELSE Workshop on Search, Mechanism Design and the Internet, UCL, London, England, June 12, 2009.
66. "Intrinsic Robustness of the Price of Anarchy," 41st Annual ACM Symposium on Theory of Computing (STOC), Bethseda, MD, June 2, 2009.
67. "The Price of Anarchy: Some Old and New Results," First Workshop of the Lund Center for Control of Complex Engineering Systems, Lund University, Lund, Sweden, May 29, 2009.
68. "Intrinsic Robustness of the Price of Anarchy," Workshop on Distributed Computing, UT Austin, Austin, TX, April 3, 2009.
69. "Intrinsic Robustness of the Price of Anarchy," Workshop on Information Theory and Applications, La Jolla, CA, February 13, 2009.
70. "Intrinsic Robustness of the Price of Anarchy," Conference on Adaptive Systems and Mechanism Design, Institute for Mathematical Behavioral Sciences at UC Irvine, Irvine, CA, January 24, 2009.
71. "Worst-Case Efficiency Analyses of Queueing Disciplines," Workshop on Networks of Networks, Institute for Pure & Applied Mathematics at UCLA, Los Angeles, CA, November 3, 2008.
72. "Potentials and Approximation," Cowles Foundation Conference on Choice, Contracts, and Computation, New Haven, CT, June 10, 2008.
73. "When Do Pure Equilibria Imply a Potential?," Caltech Microeconomic Dynamics Workshop, Pasadena, CA, May 24, 2008.

74. "When Do Pure Equilibria Imply a Potential?," Fifth Bay Algorithmic Game Theory Symposium (BAGT), Mountain View, CA, April 11, 2008.

75. "Optimal Protocol Design in Networks with Selfish Users," Forty-Fifth Annual Allerton Conference on Communication, Control, and Computing, Monticello, IL, September 26, 2007.

76. "Optimal Protocol Design in Networks with Selfish Users," Fourth ACM SIGACT-SIGOPS International Workshop on Foundations of Mobile Computing (DIAL-M), Portland, OR, August 16, 2007.

77. "Optimal Protocol Design in Networks with Selfish Users," Dagstuhl Workshop on Computational Social Systems and the Internet, Wadern, Germany, July 2, 2007.

78. "Approximately Efficient, Budget-Balanced Cost-Sharing Mechanisms," Society for the Advancement of Economic Theory Conference on Current Trends in Economics (SAET), Kos, Greece, June 22, 2007.

79. "Single-Source Stochastic Routing," 9th International Workshop on Approximation Algorithms for Combinatorial Optimization Problems (APPROX), Barcelona, Spain, August 30, 2006.

80. "Potential Functions and the Inefficiency of Equilibria," International Congress of Mathematicians (ICM), Madrid, Spain, August 29, 2006.

81. "Optimal Cost-Sharing Mechanisms," CRM Workshop on Network Design: Optimization and Algorithmic Game Theory, Montreal, Canada, August 16, 2006.

82. "Quantifying the Inefficiency of Wardrop Equilibria," INFORMS Annual Meeting, San Francisco, CA, November 14, 2005.

83. "New Trade-Offs in Cost-Sharing Mechanisms," Aladdin Workshop on Flexible Network Design, Princeton, NJ, November 5, 2005.

84. "Computing Correlated Equilibria in Multi-Player Games," Conference on Foundations of Computational Mathematics (FoCM), Santander, Spain, July 5, 2005.

85. "Computing Correlated Equilibria in Multi-Player Games," Third Bertinoro Workshop on Random Graphs and Randomized Algorithms (RGRAALS), Bertinoro, Italy, June 22, 2005.

86. "Computing Correlated Equilibria in Multi-Player Games," Dagstuhl Workshop on Design and Analysis of Randomized and Approximation Algorithms, Wadern, Germany, May 18, 2005.

87. "Selfish Routing with Atomic Players," 16th Annual ACM-SIAM Symposium on Discrete Algorithms (SODA), Vancouver, CA, January 25, 2005.

88. "Computing Equilibria in Multi-Player Games," 16th Annual ACM-SIAM Symposium on Discrete Algorithms (SODA), Vancouver, Canada, January 23, 2005.

89. "Selfish Routing and the Price of Anarchy," National Academy of Sciences Beckman Frontiers of Science Symposium, Irvine, CA, November 5, 2004.

90. "Bounding Braess's Paradox," INFORMS Annual Meeting, Denver, CO, October 25, 2004.

91. "Bounding Braess's Paradox," Workshop on Economic Aspects of Congested Networks and Queues, Bonn, Germany, July 10, 2004.

92. "Computing (Correlated) Equilibria in Multi-Player Games," First Bertinoro Workshop on Algorithmic Game Theory, (AGATE), Bertinoro, Italy, July 5, 2004.

93. "Bounding Braess's Paradox," First Bertinoro Workshop on Combinatorial Optimization, (BECO), Bertinoro, Italy, May 3, 2004.

94. "The Maximum Latency of Selfish Routing," 15th Annual ACM-SIAM Symposium on Discrete Algorithms (SODA), New Orleans, LA, January 13, 2004.

95. "The Price of Anarchy Is Independent of the Network Topology," INFORMS Annual Meeting, Atlanta, GA, October 21, 2003.
96. "Selfish Routing," 18th International Symposium on Mathematical Programming (ISMP), Copenhagen, Denmark, August 19, 2003.
97. "Pricing Networks with Selfish Routing," Dagstuhl Workshop on Algorithmic Game Theory and the Internet, Wadern, Germany, July 16, 2003.
98. "How Much Can Taxes Help Selfish Routing?" 4th Annual ACM Conference on Electronic Commerce (EC), San Diego, CA, June 11, 2003.
99. "Pricing Network Edges with Heterogeneous Selfish Users," 35th Annual ACM Symposium on Theory of Computing (STOC), San Diego, CA, June 11, 2003.
100. "Pricing Networks with Selfish Routing," Workshop on Economics of Peer-to-Peer Networks, Berkeley, CA, June 5, 2003
101. "Selfish Routing and the Price of Anarchy," Annual AAAS Meeting, Denver, CO, February 14, 2003.
102. "Designing Networks for Selfish Users Is Hard," Dagstuhl Workshop on Approximation and Randomized Algorithms in Communication Networks, Wadern, Germany, June 16, 2002.
103. "The Price of Anarchy Is Independent of the Network Topology," 34th Annual ACM Symposium on Theory of Computing (STOC), Montreal, Canada, May 20, 2002.
104. "How Unfair Is Optimal Routing?," 13th Annual Symposium on Discrete Algorithms (SODA), San Francisco, CA, January 6, 2002.
105. "Designing Networks for Selfish Users Is Hard," DIMACS Workshop on Computational Issues in Game Theory and Mechanism Design, Rutgers University, Piscataway, NJ, October 31, 2001.
106. "Designing Networks for Selfish Users Is Hard," 42nd Annual Symposium on Foundations of Computer Science (FOCS), Las Vegas, NY, October 17, 2001.
107. "Stackelberg Scheduling Strategies," 33rd Annual ACM Symposium on Theory of Computing (STOC), Hersonissos, Crete, Greece, July 6, 2001.
108. "Approximate k-MSTs and k-Steiner Trees via the Primal-Dual Method and Lagrangean Relaxation," Eighth Conference on Integer Programming and Combinatorial Optimization (IPCO), Utrecht, The Netherlands, June 15, 2001.
109. "How Bad Is Selfish Routing?," 41st Annual Symposium on Foundations of Computer Science (FOCS), Redondo Beach, CA, November 12, 2000.
110. "How Bad Is Selfish Routing?," 17th International Symposium on Mathematical Programming (ISMP), Atlanta, GA, August 10, 2000.

Courses Taught (Columbia)

1. Fall 2020: COMS 6998, Foundations of Blockchains, 42 students.
2. Spring 2020: COMS 4995, Incentives in Computer Science, 43 students.
   Evaluation score (only midterm evaluations available): 4.7/5.0.
3. Fall 2019: COMS 4995, Randomized Algorithms, 45 students.
   Overall evaluation score: 4.9/5.0.

Courses Taught (Stanford)

1. Fall 2018: CS269I, Incentives in Computer Science, 130 students.
   Overall evaluation score: 4.8/5.0.
2. Spring 2017: CS168, The Modern Algorithmic Toolbox, 126 students. (Co-taught with Greg Valiant.)
   Overall evaluation score: 4.7/5.0.
3. Winter 2017: CS264, Beyond Worst-Case Analysis, 31 students.
   Overall evaluation score: 5.0/5.0.
4. Fall 2016: CS269I, Incentives in Computer Science, 52 students.
   Overall evaluation score: 4.9/5.0.
5. Spring 2016: CS168, The Modern Algorithmic Toolbox, 88 students. (Co-taught with Greg Valiant.)
   Overall evaluation score: 4.6/5.0.
6. Spring 2016: CS167, Readings in Algorithms, 8 students.
   Overall evaluation score: 4.9/5.0.
7. Winter 2016: CS261, Optimization and Algorithmic Paradigms, 52 students. Overall evaluation score: 4.8/5.0.
8. Spring 2015: CS261, Optimization and Algorithmic Paradigms, 72 students. Overall evaluation score: 4.7/5.0.
9. Spring 2015: CS168, The Modern Algorithmic Toolbox, 81 students. (Co-taught with Greg Valiant.)
   Overall evaluation score: 4.9/5.0.
10. Winter 2015: CS369E, Communication Complexity (for Algorithm Designers), 11 students.
    Overall evaluation score: 5.0/5.0.
11. Fall 2014: CS264, Beyond Worst-Case Analysis, 15 students.
    Overall evaluation score: 4.9/5.0.
12. Spring 2014: CS167, Readings in Algorithms, 14 students.
    Overall evaluation score: 5.0/5.0.
13. Winter 2014: CS364B, Frontiers in Mechanism Design, 12 students.
    Overall evaluation score: 4.8/5.0.
14. Fall 2013: CS364A, Algorithmic Game Theory, 52 students.
    Overall evaluation score: 4.9/5.0.
15. Fall 2011: CS161, Design and Analysis of Algorithms, 199 students.
    Overall evaluation score: 4.6/5.0.
16. Fall 2011: CS369N, Beyond Worst-Case Analysis, 18 students.
    Overall evaluation score: 5.0/5.0.
17. Winter 2011: CS161, Design and Analysis of Algorithms, 123 students.
    Overall evaluation score: 4.7/5.0.
18. Winter 2011: CS364A, Algorithmic Game Theory, 24 students.
    Overall evaluation score: 4.8/5.0.
19. Winter 2010: CS161, Design and Analysis of Algorithms, 164 students.
    Overall evaluation score: 4.7/5.0.
20. Fall 2009: CS369N, Beyond Worst-Case Analysis, 17 students.
    Overall evaluation score: 4.9/5.0.
21. Winter 2009: CS161, Design and Analysis of Algorithms, 118 students.
    Overall evaluation score: 4.7/5.0.

22. Fall 2008: CS364A, Algorithmic Game Theory, 38 students.
Overall evaluation score: 4.8/5.0.
23. Winter 2008: CS161, Design and Analysis of Algorithms, 116 students.
Overall evaluation score: 4.5/5.0.
24. Winter 2008: CS369B, Advanced Graph Algorithms, 18 students.
Overall evaluation score: 4.7/5.0.
25. Fall 2007: Foundations of Sponsored Search, 28 students.
Overall evaluation score: 4.7/5.0.
26. Winter 2007: CS161, Design and Analysis of Algorithms, 102 students.
Overall evaluation score: 4.6/5.0.
27. Winter 2007: CS359D, Hardness of Approximation, 16 students.
Overall evaluation score: 4.7/5.0.
28. Fall 2006: CS364A, Algorithmic Game Theory, 32 students.
Overall evaluation score: 4.8/5.0.
29. Winter 2006: CS161, Design and Analysis of Algorithms, 91 students.
Overall evaluation score: 4.7/5.0.
30. Winter 2006: CS369C, Metric Embeddings and Algorithmic Applications, 22 students.
Overall evaluation score: 4.6/5.0
31. Fall 2005: CS364B, Topics in Algorithmic Game Theory, 27 students.
Overall evaluation score: 4.4/5.0
32. Winter 2005: CS161, Design and Analysis of Algorithms, 101 students.
No scores available.
33. Fall 2004: CS364A, Algorithmic Game Theory, 22 students.
No scores available.

PhD Supervision

1. Maryam Bahrani (expected 2025)
2. William Brown (expected 2024) [co-advised with Christos Papadimitriou]
3. Eric Neyman (expected 2024)
4. Vaggos Chatziafratis (2020) [Thesis: Hierarchical Clustering with Global Objectives: Approximation Algorithms and Hardness Results]
5. Warut Suksompong (2018) [Thesis: Resource Allocation and Decision Making for Groups]
6. Joshua Wang (2018) [Thesis: Theoretical Models for Practical Problems: Dynamic Data Structures, Hierarchical Clustering, and Modern Parallel Computing]
7. Okke Schrijvers (2017) [Thesis: Learning and Incentives in Computer Science]
8. Rishi Gupta (2016) [Thesis: Theoretical Foundations for Practical Problems: Network Analysis, Algorithm Selection, and Interaction Design]
9. Inbal Talgam-Cohen (2015) [Thesis: Robust Market Design: Information and Computation]
10. Kostas Kollias (2015) [Thesis: Sharing Costs to Optimize Network Equilibria]

11. Kshipra Bhawalkar (2013) [Thesis: Approximation Guarantees for Game-theoretic Equilibria]
12. Qiqi Yan (2012) [Thesis: Prior-Independence: A New Lens for Mechanism Design]
13. Peerapong Dhangwatnotai (2011) [Thesis: Auction Design with Robust Guarantees]
14. Shaddin Dughmi (2011) [Thesis: Randomization and Computation in Strategic Settings (Arthur L. Samuel Thesis Award)]
15. Aneesh Sharma (2011) [Thesis: Algorithmic Problems in Social and Geometric Influence]
16. Damon Mosk-Aoyama (2010) [Thesis: Convergence To and Quality of Equilibria in Distributed Systems]
17. Mukund Sundararajan (2009) [Thesis: Trade-Offs in Cost-Sharing]

Postdoctoral Supervision

1. Kira Goldner (2019–2021)
2. Rad Niazadeh (2017–2019)
3. Vasilis Gkatzelis (2013–2015)
4. Paul Dütting (2013–2014)
5. Zhiyi Huang (2013–2014)
6. Uri Nadav (2009–2011)
7. Florian Schoppmann (2009–2010)
8. Martin Hoëfer (2008)
9. Shuchi Chawla (2006)

Organized Conferences, Workshops, and Programs

1. General Chair, TheoryFest, 53rd Annual ACM Symposium on Theory of Computing (STOC), Rome, Italy, June 2021.
2. General Chair, TheoryFest, 52nd Annual ACM Symposium on Theory of Computing (STOC), June 2020.
3. Co-Organizer, PapaFest (Christos Papadimitriou's 70th Birthday Conference), Columbia University, New York, NY, September 2019.
4. Co-Organizer, Workshop on Learning and Strategic Behavior, 18th Annual ACM Conference on Economics and Computation (EC), Phoenix, AZ, June 2019.
5. Co-Organizer, Workshop on Learning and Strategic Behavior, Toyota Technological Institute at Chicago, IL, August 2018.
6. Chair, Keynotes and Tutorials Committee, 50th Annual ACM Symposium on Theory of Computing (STOC), Los Angeles, CA, June 2018.
7. Tutorials Chair, 29th International Conference on Algorithmic Learning Theory (ALT), Lanzarote, Spain, April 2018.
8. Co-Organizer, Donald Knuth's 80th Birthday Workshop, Piteå, Sweden, January 2018.

9. Co-Organizer, Workshop on Learning in the Presence of Strategic Behavior, 31st Annual Conference on Neural Information Processing Systems (NIPS), December 2017.
10. Chair, Keynotes and Tutorials Committee, 49th Annual ACM Symposium on Theory of Computing (STOC), Montreal, Canada, June 2017.
11. Co-Organizer, Workshop on Learning, Algorithm Design, and Beyond Worst-Case Analysis, Simons Institute for the Theory of Computing, Berkeley, CA, November 2016.
12. Co-Organizer, Special Semester on Economics and Computation, Simons Institute for the Theory of Computing, Berkeley, CA, August–December 2015.
13. Co-Organizer, Workshop on Algorithmic Game Theory and Practice, Simons Institute for the Theory of Computing, Berkeley, CA, November 2015.
14. Co-Organizer, Boot Camp on Economics and Computation, Simons Institute for the Theory of Computing, Berkeley, CA, August 2015.
15. General Chair, 16th Annual ACM Conference on Electronic Commerce (EC), Portland, OR, June 2015.
16. Co-Organizer, Dagstuhl Workshop on Beyond Worst-Case Analysis, Wadern, Germany, September 2014.
17. General Co-Chair, 45th Annual ACM Symposium on Theory of Computing (STOC), Stanford, CA, June 2013.
18. Co-Organizer, Summer School on Algorithmic Economics, Pittsburgh, PA, August 2012.
19. Organizer, Workshop on Beyond Worst-Case Analysis, Stanford, CA, September 2011.
20. Organizer, Motwani Distinguished Lecture Series, Stanford, CA, 2011–present.
21. Co-Organizer, Bertinoro Workshop on Frontiers in Mechanism Design, Bertinoro, Italy, March 2010.
22. Scientific Committee Member, Special Semester on Distributed Decision-Making and Control, LCCC Linnaeus center, Lund University, Sweden, January–June 2010.
23. Cluster Co-Chair (Game Theory), 20th International Symposium on Mathematical Programming (ISMP), Chicago, IL, August 2009.
24. Cluster Co-Chair (Game Theory), INFORMS Annual Meeting, Seattle, WA, November 2007.
25. Co-Organizer, 2nd Bertinoro Workshop on Algorithmic Game Theory (AGATE), Bertinoro, Italy, July 2006.
26. Co-Organizer, Bay Algorithmic Game Theory Symposium (BAGT), Mountain View, CA, February 2006, September 2006, April 2007, October 2007, and April 2008.
27. Co-Organizer, Bay Area Theory Symposium (BATS), Stanford, CA, November 2005, December 2006, and December 2007.
28. Tutorials and Workshops Chair, 6th Annual ACM Conference on Electronic Commerce (EC), Vancouver, British Columbia, Canada, June 2005.
29. Organizer, Stanford Algorithms Seminar (AFLB), Stanford, CA, 2005–2012.

Program Committees (Chair)

1. Program Committee Chair, 6th Conference on Innovations in Theoretical Computer Science (ITCS), Weizmann, Israel, January 2015.

2. Program Committee Chair, 53rd Annual Symposium on Foundations of Computer Science (FOCS), New Brunswick, NY, October 2012.
3. Program Committee Co-Chair, 12th Annual ACM Conference on Electronic Commerce (EC), San Jose, CA, June 2011.
4. Program Committee Co-Chair, First Workshop on the Economics of Networked Systems (NetEcon), Ann Arbor, MI, June 2006.

Program Committees

1. Program Committee Member, Second ACM Conference on Advances in Financial Technology (AFT), New York, NY, October 2020.
2. Senior Program Committee Member, 21st Annual ACM Conference on Economics and Computation (EC), Budapest, Hungary, July 2020.
3. Senior Program Committee Member, 28th International Joint Conference on Artificial Intelligence (IJCAI), Macao, China, August 2019.
4. Senior Program Committee Member, 20th Annual ACM Conference on Economics and Computation (EC), Pheonix, AZ, June 2019.
5. Program Committee Member, 2nd Symposium on Simplicity in Algorithms (SOSA), San Diego, CA, January 2019.
6. Program Committee Member, 59th Annual Symposium on Foundations of Computer Science (FOCS), Paris, France, October 2018.
7. Program Committee Member, 35th International Conference on Machine Learning (ICML), Stockholm, Sweden, July 2018.
8. Program Committee Member, 29th International Conference on Algorithmic Learning Theory (ALT), Lanzarote, Spain, April 2018.
9. Senior Program Committee Member, 18th Annual ACM Conference on Economics and Computation (EC), Cambridge, MA, June 2017.
10. Program Committee Member, 2nd Conference on Highlights of Algorithms (HALG), Berlin, Germany, June 2017.
11. Program Committee Member, 8th Conference on Innovations in Theoretical Computer Science (ITCS), Berkeley, CA, January 2017.
12. Program Committee Member, Fifth World Congress of the Game Theory Society, Maastricht, Netherlands, July 2016.
13. Program Committee Member, 15th Annual ACM Conference on Electronic Commerce (EC), Stanford, CA, June 2014.
14. Program Committee Member, 9th International Workshop on Internet & Network Economics (WINE), Cambridge, MA, December 2013.
15. Senior Program Committee Member, 14th Annual ACM Conference on Electronic Commerce (EC), Philadelphia, PA, June 2013.
16. Program Committee Member, Fourth World Congress of the Game Theory Society, Istanbul, Turkey, July 2012.
17. Senior Program Committee Member, 13th Annual ACM Conference on Electronic Commerce (EC), Valencia, Spain, June 2012.

18. Program Committee Member, 52nd Annual Symposium on Foundations of Computer Science (FOCS), Palm Springs, CA, October 2011.

19. Program Committee Member, 6th International Workshop on Internet & Network Economics (WINE), Stanford, CA, December 2010.

20. Program Committee Member, 11th Annual ACM Conference on Electronic Commerce (EC), Cambridge, MA, June 2010.

21. Program Committee Member, Sixth Workshop on Ad Auctions, Cambridge, MA, June 2010.

22. Program Committee Member, 19th International World Wide Web Conference (WWW), Raleigh, NC, April 2010.

23. Program Committee Member, 5th International Workshop on Internet & Network Economics (WINE), Rome, Italy, December 2009.

24. Program Committee Member, 50th Annual Symposium on Foundations of Computer Science (FOCS), Atlanta, GA, November 2009.

25. Program Committee Member, 12th International Workshop on Approximation Algorithms for Combinatorial Problems (APPROX), Berkeley, CA, August 2009.

26. Program Committee Member, 28th Annual ACM SIGACT-SIGOPS Symposium on Principles of Distributed Computing (PODC), August 2009.

27. Senior Program Committee Member, 10th Annual ACM Conference on Electronic Commerce (EC), Stanford, CA, July 2009.

28. Program Committee Member, Workshop on the Economics of Networks, Systems, and Computation (NetEcon), Stanford, CA, July 2009.

29. Program Committee Member, SIGCOMM Workshop on the Economics of Networks, Systems, and Computation (NetEcon), Seattle, WA, August 2008.

30. Program Committee Member, Third World Congress of the Game Theory Society, Evanston, IL, July 2008.

31. Program Committee Member, Fourth Workshop on Ad Auctions, Chicago, IL, July 2008.

32. Program Committee Member, 9th Annual ACM Conference on Electronic Commerce (EC), Chicago, IL, July 2008.

33. Program Committee Member, 35th International Symposium on Automata, Languages, and Programming (ICALP), Reykjavik, Iceland, July 2008.

34. Program Committee Member, 17th International World Wide Web Conference (WWW), Beijing, China, April 2008.

35. Program Committee Member, First Symposium on Algorithmic Game Theory (SAGT), Paderborn, Germany, April 2008.

36. Program Committee Member, Third International Workshop on Internet & Network Economics (WINE), San Diego, CA, December 2007.

37. Program Committee Member, 26th Annual ACM SIGACT-SIGOPS Symposium on Principles of Distributed Computing (PODC), Portland, OR, August 2007.

38. Program Committee Member, Second Workshop on the Economics of Networked Systems (NetEcon), San Diego, CA, June 2007.

39. Program Committee Member, 19th ACM Symposium on Parallelism in Algorithms and Architectures (SPAA), San Diego, CA, June 2007.
40. Program Committee Member, 18th Annual Symposium on Discrete Algorithms (SODA), New Orleans, LA, January 2007.
41. Program Committee Member, Second International Workshop on Incentive Based Computing (IBC), Lisboa, Portugal, July 2006.
42. Program Committee Member, 33rd International Symposium on Automata, Languages, and Programming (ICALP), Venice, Italy, July 2006.
43. Program Committee Member, First International Workshop on Incentive Based Computing (IBC), Compiegne, France, September 2005.
44. Program Committee Member, Third Workshop on the Economics of Peer-to-Peer Systems (P2PECON), Philadelphia, PA, August 2005.
45. Program Committee Member, 2005 Workshop on Combinatorial and Algorithmic Aspects of Networking (CAAN), Waterloo, Ontario, Canada, August 2005.
46. Program Committee Member, 37th Annual ACM Symposium on Theory of Computing (STOC), Baltimore, MD, May 2005.
47. Program Committee Member, SIGCOMM Workshop on Practice and Theory of Incentives in Networked Systems (PINS), Portland, OR, August 2004.
48. Program Committee Member, 7th International Workshop on Approximation Algorithms for Combinatorial Problems (APPROX), Cambridge, MA, August 2004.
49. Program Committee Member, Workshop on Combinatorial and Algorithmic Aspects of Networking (CAAN), Banff, Alberta, Canada, August 2004.

Editorial Boards

Associate Editor (Research Highlights), Communications of the ACM, 2017–present.

Editor, Games and Economic Behavior, 2016–present.

Area Editor (Economics and Computation), Journal of the ACM, 2015–present.

Associate Editor, SIAM Journal on Computing, 2012–2018.

Associate Editor, Mathematics of Operations Research, 2012–2017.

Advisory Editor, Games and Economic Behavior, 2008–2016.

Associate Editor, SIAM Journal on Discrete Mathematics, 2012–2016.

Associate Editor, ACM Transactions on Economics and Computation, 2011–2015.

Associate Editor, ACM Transactions on Algorithms, 2005–2014.

Associate Editor, Operations Research Letters, 2004–2011.

Guest Editor, SIAM Journal on Computing, Special Issue on Selected Papers from the FOCS 2012 Conference.

Guest Editor, Games and Economic Behavior, Special Issue on Algorithmic Game Theory in the SODA, STOC, and FOCS Conferences, 2011.

Guest Editor, Games and Economic Behavior, Special Issue on ACM EC 2010 and 2011 Conferences, 2011.

Guest Editor, IEEE Journal on Selected Areas in Communication, Special Issue on Non-Cooperative Issues in Networking, 2007.

Additional Professional Service

Chair, National Science Foundation CCF Division Director Search Committee, August–October 2017.

Chair, Committee for the Advancement of Theoretical Computer Science (CATCS), August 2015–July 2018.

Member, Committee for the Advancement of Theoretical Computer Science (CATCS), July 2013–June 2019.

Steering Committee Member, Innovations in Theoretical Computer Science (ITCS) Conference, 2016–present.

Council of the Game Theory Society, 2013–present.

Scientific Advisory Board, Simons Foundation Institute for the Theory of Computing, 2012–2015.

Vice Chair, ACM SIGEcom, 2011–2015.

References

Available upon request.

EXHIBIT 2

Materials Relied Upon

Articles and Books:

Dughmi, Shaddin, Roughgarden, T, and Yan, Q. (2016). "Optimal Mechanisms for Combinatorial Auctions and Combinatorial Public Projects via Convex Rounding," *Journal of the ACM*, 63(4): Article 30, September 2016.

Neil Newman, Kevin Leyton-Brown, Paul Milgrom, and Ilya Segal, "Incentive Auction Design Alternatives: A Simulation Study," Proceedings of the ACM Conference on Economics and Computation, pages 603—604, 2020.

Nisan, N., Roughgarden, T., Tardos, E., and Vazirani, V. (Eds.). (2007). *Algorithmic Game Theory.* Cambridge: Cambridge University Press.

Roughgarden, T. (2016). *Twenty Lectures on Algorithmic Game Theory*. Cambridge: Cambridge University Press.

Roughgarden, T. (2010). "Algorithmic Game Theory," *Communications of the ACM*, July 2010, Vol. 53 No. 7, Pages 78-86. https://cacm.acm.org/magazines/2010/7/95063-algorithmic-game-theory/fulltext

Roughgarden, T., Talgam-Cohen, I., and Yan, Q. "Robust Auctions for Revenue via Enhanced Competition," *Operations Research,* 68(4):1074--1094, June 2020.

Documents:

Deposition of Chinmay Karande

Expert Report of Armando Levy, Appendix D

Expert Report of Dr. Greg Allenby

Exhibit 120 to the Deposition of Dr. Chinmay Karande

Exhibit 121 to the Deposition of Dr. Chinmay Karande

Exhibit 122 to the Deposition of Dr. Chinmay Karande

Exhibit 123 to the Deposition of Dr. Chinmay Karande

Exhibit 124 to the Deposition of Dr. Chinmay Karande

Exhibit 125 to the Deposition of Dr. Chinmay Karande

Exhibit 126 to the Deposition of Dr. Chinmay Karande

Exhibit 127 to the Deposition of Dr. Chinmay Karande

Exhibit 128 to the Deposition of Dr. Chinmay Karande

Exhibit 129 to the Deposition of Dr. Chinmay Karande

Exhibit 130 to the Deposition of Dr. Chinmay Karande

Exhibit 131 to the Deposition of Dr. Chinmay Karande

Exhibit 132 to the Deposition of Dr. Chinmay Karande

Facebook Inc.'s Amended and Supplemental Responses to Interrogatory No. 5, *DZ Reserve v. Facebook, Inc.*

FB-SINGER-00088221

FB-SINGER-00089483

FB-SINGER-00089484

FB-SINGER-00150228

FB-SINGER-00186795

FB-SINGER-00186888

FB-SINGER-00186952

FB-SINGER-00187088

FB-SINGER-00187518

FB-SINGER-00187567

FB-SINGER-00313499

FB-SINGER-00314707

Plaintiffs' Third Amended Consolidated Class Action Complaint, *DZ Reserve v. Facebook, Inc.*

APPENDIX A

Appendix A: Sensitivity Analyses

Figure 5: Conjoint GSP Advertiser CPM Ratios (20 Trials, Combined)

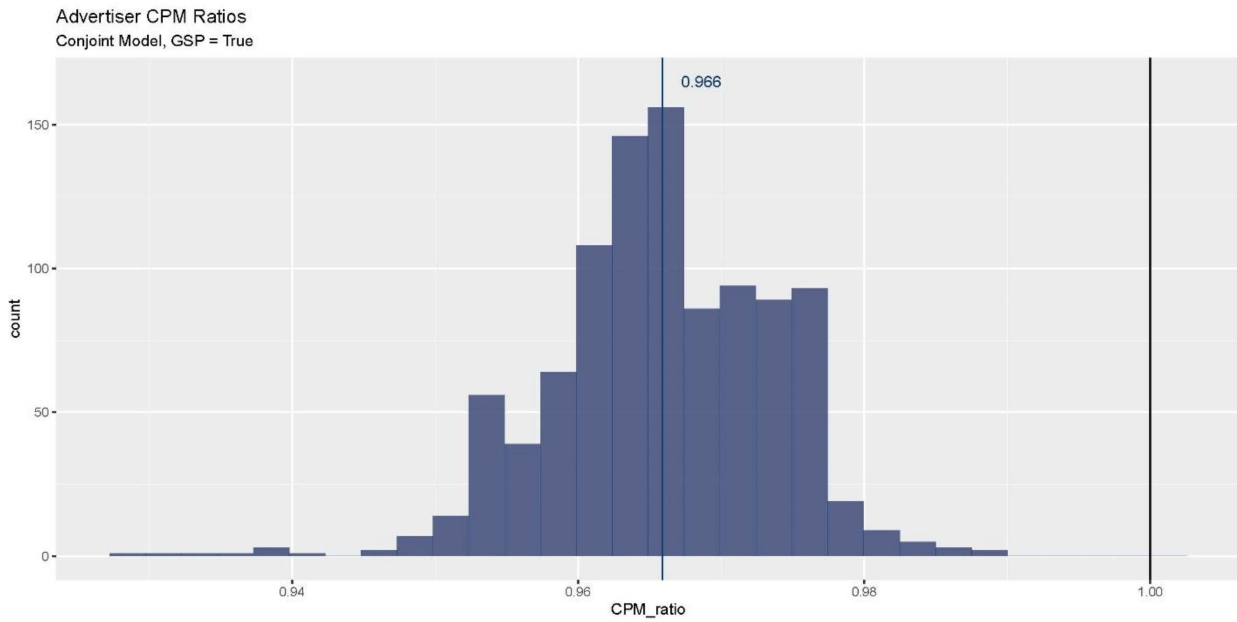
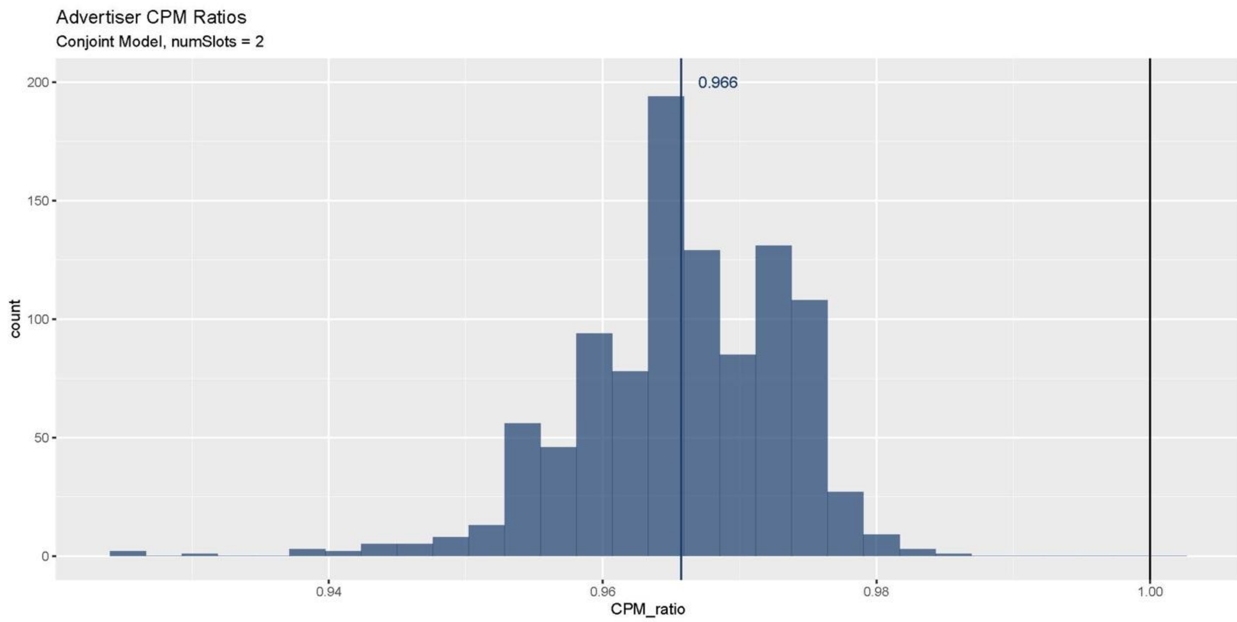


Figure 6: Conjoint VCG with Two Slots – CPM Ratios (20 Trials, Combined)



[redacted]

[redacted]

[redacted]

Figure 9: Removal of Potential Reach - GSP Advertiser CPM Ratios (20 Trials, Combined)

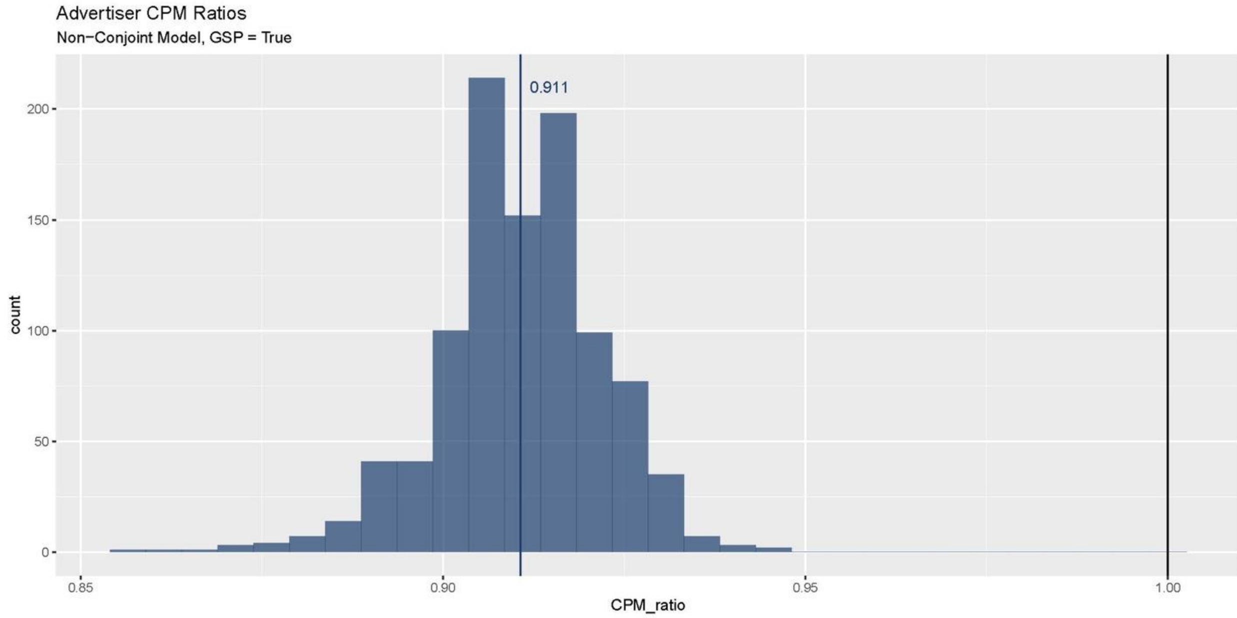
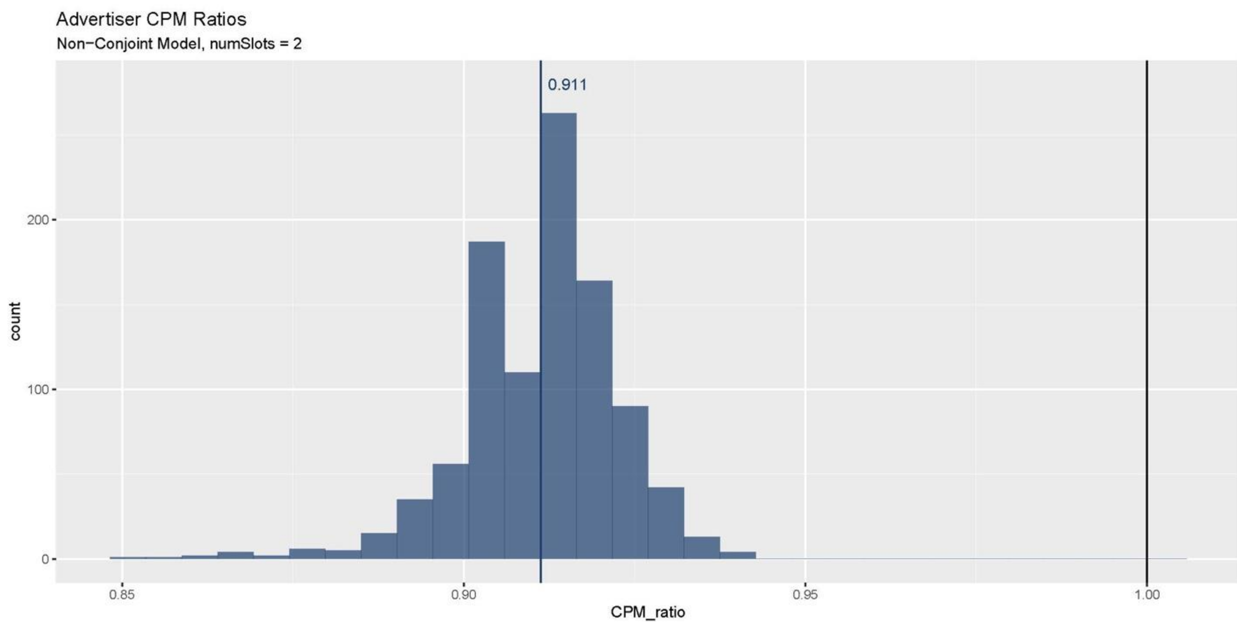


Figure 10 – Removal of Potential Reach – Two Slot VCG – CPM Ratios (20 Trials, Combined)



[redacted]

[redacted]

[redacted]

[redacted]

APPENDIX B

Appendix B: Parameter Settings

In setting the parameters for my Facebook Auction Simulation, I scaled the parameters vis-à-vis the other parameters to approximate the corresponding ratios in Facebook's auctions.

Among the parameters I set:

- For the budget distribution, I am relying on Dr. Armando Levy's analysis of Facebook's budget data, which was produced as FB-SINGER-00314707. In order to scale the budget distribution to 50 advertisers, a budget limit was set so that no single advertiser's budget would represent an unreasonably large fraction of the sum of all advertisers' budgets. [redacted] Accordingly, I set the budget limit to $100. On average, an advertiser with a budget of $100 would control [redacted] of the overall spend.

- I set the number of advertisement slots to [redacted] based on FB-SINGER-00187567, which shows [redacted].

- I set the organic ratio at [redacted] based on FB-SINGER-00186952, which shows that [redacted]

[1] Appendix D of Expert Report of Armando Levy.

APPENDIX C

Appendix C: Data Not Produced or Not Produced in Usable Format

It is my understanding that a significant amount of data requested by the Plaintiffs was not produced by Defendant Facebook, Inc. or was produced in an unusable format. This includes:

- Documents sufficient to show the average number of advertisements and the average number of organic stories for which there are bids per auction, per day, and per month.

- Documents sufficient to show the average number of winning advertisements and the average number of wining organic stories per auction, per day, and per month.

- Facebook produced maximum bid data in an unusable format. Facebook produced the field "[redacted]," which states: "[redacted]." FB-SINGER-00313499 (emphasis in the original).

- Documents sufficient to show the losing bids in Facebook's auction.